RESULTS OF AN INVESTIGATION

ON THE REMOVAL OF A RADIOACTIVE

ISOTOPE ($I^{131}$) FROM SEWAGE BY THE USE

OF LABORATORY TRICKLING FILTERS

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ABSTRACT

An initial literature survey was conducted to gain background information on trickling filter theory and operation and to find out what had been done on employing biological treatment to problems in radioactive waste disposal. Additional "library research" was done to familiarize the author with the basic fundamentals of nuclear physics and precautions to be observed when working with radioactive materials.

Four laboratory trickling filter columns were operated at three dosage rates, all in the standard or low rate range, to determine their operational characteristics and to facilitate comparison with similar filters used for ordinary sewage treatment. Due to its widespread usage in the sanitary engineering field, the biochemical oxygen demand (B.O.D.) test was used as the criterion for filter operation.

Settled sewage, spiked with known amounts of radioactive iodine ($I^{131}$), was passed through the filter columns and the removal of activity determined at any one of six sampling points located at various filter depths. This arrangement provided data for the correlation of filter depth, dosage rate and removal of activity.

The results of 34 runs utilizing B.O.D. data are presented as well as the results of 15 runs employing radioactive sewage as a test material. Several special investigations are included and thought directed toward others.

The data indicate that the filters were operating normally with respect to B.O.D. removal and that $I^{131}$ may be removed from certain contaminated wastes by treatment with trickling filters. When using a concentration of 1,000 counts per minute per milliliter (c/m/ml) of carrier-free $I^{131}$, removals of $I^{131}$ in excess of 85 per cent were obtained at a dosage rate of two million gallons per acre per day (mgad).

# INTRODUCTION

The use of trickling filters for secondary treatment of wastes in the United States dates back to the beginning of the Lawrence Experiment Station.[1] Under the able guidance of its director, Colonel George E. Waring, Jr., trickling filters were used successfully for the oxidation of sewage.

A trickling filter may be defined as:[2]

> "A filter consisting of an artificial bed of coarse material, such as broken stone, clinkers, slate, slats, or brush, over which sewage is distributed and applied in drops, films, or spray, from troughs, drippers, moving distributors, or fixed nozzles, and through which it trickles to the underdrains, giving opportunity for the formation of zoogleal slimes which clarify and oxidize the sewage."

Another definition is that given by Franks:[3]

> "A trickling filter, which is not a filter in the usual sense, may be defined as a bed of filtering media of various kinds, sizes, and shapes; and of varying depths and areas; over which settled sewage is distributed by diverse means and at different rates; and where the sewage, upon trickling through, is so altered in character by complex biotic, chemical, and physical means as to render it sufficiently stable to be innocuous to health and to prevent nuisance downstream."

This discrepancy between name and function is clarified further by Walton[4] who states:

> "It is not in a true sense a filtration process. The interspaces between the rock are many times the size of the suspended and colloidal solids; moreover, the need for the filter to 'mature' or 'ripen' cannot be explained by the filtration theory."

A brief history of trickling filters may be had by consulting Jones[1] and Chase.[5] Jones states that a standard rate trickling filter is a dependable and reliable device for oxidation of sewage.

This is borne out by the fact that a survey in 27 states conducted by Stanley[6] in 1938 showed that the ratio of trickling filter plants to activated sludge plants was about 6.5 to 1, whereas the population represented was only about 2.1 to 1. This indicates the use of trickling filters in the smaller treatment plants. Stanley's survey included 657 trickling filter plants and a population of approximately seven million.

Another indication of the trickling filters' importance in sewage treatment is the fact that during World War II more than one-half of sewage treatment plants installed at military posts included trickling filters.[7] This includes both high rate and conventional or standard rate units.

Before a discussion of the nature of the trickling filter process, let us look briefly at the predominate type of waste treated, namely domestic sewage. Sewage is defined in the book, Glossary - Water and Sewage Control Engineering,[2] as "largely the water supply of a community after it has been fouled by various uses," and domestic sewage as "sewage derived principally from dwellings, business buildings, institutions, and the like." A more informative definition is that given by Hood.[8] He describes sewage as being "a heterogeneous combination of organic and inorganic, suspended, colloidal and dissolved solids, dispersed in large quantities of water." He goes a step further by saying that it is also helpful to think of sewage as a nutrient medium (a food) for the promotion of the life of certain desirable organisms and hence their helpful activities. The constituents of sewage are discussed by Gehm,[9] Keefer,[10] and Metcalf and Eddy.[11]

As to the nature of the trickling filter process I should, in all fairness, say that it is not entirely understood. The process is primarily biological in nature. Lackey[12] states that the biologic action has long been known to take place. The fact that it does take place is our primary concern at present. Walton[4] describes the secondary treatment of sewage (an oxidation process) as a process whereby "the complex organic matter becomes entrapped, either by adhesion or absorption, in a living floc or film of bacteria and protozoa. In the presence of free oxygen this matter is acted on by the organisms and their enzymes to produce substance of greater stability." He further describes the process as one involving the absorption by the zooglea (viscous, jelly-like substance containing living organisms) of the organic material contained in the sewage as it passes over the filter medium in thin layers. The organic material removed consists of suspended, colloidal and dissolved materials.

Imhoff and Fair[13] point out the various things that the process has been attributed to but conclude that: "Whatever the individual operations of contact action may be, it is certain that the work of purification is associated with the life activities of the microorganisms that create and maintain the active interfaces. Their well-being is essential to the process."

The organic matter that the filter retains is indefinitely held in the filter and chemical changes take place which are the result of the activities of the organisms and their enzymes contained in the zooglea. This material is passed from the filter during periods of sloughing.

Heukelekian[14] states that:

> "The quantity of film in a filter bed is determined by the net effect of two opposing factors, (1) accumulation and (2) unloading and oxidation. The accumulation is the result of removal of solids from the sewage applied and the growth of the flora and fauna. The film consists of (1) living and dead cells of the biological population, (2) organic matter retained from sewage at different stages of decomposition, and (3) digested and undigested organic residues."

When working with trickling filters, some method or procedure must be used which will facilitate the interpretation of the data and serve as a measuring stick. The biochemical oxygen demand (B.O.D.) test has long been recognized in the sanitary engineering field as such a method. This is evident by its past and present widespread use. Schaetzle[15] points out that the dissolved oxygen (D.O.) and B.O.D. tests are our most reliable servants when dealing with trickling filters. Ridenour[16] presents a discussion on the use of the B.O.D. test in filter work and also gives other very useful concepts for expressing loadings and efficiencies.

For an understanding of the functions of trickling filters certain essential factors must be kept in mind in relation to their predominately biological nature. These factors seem to be (1) food supply; (2) oxygen supply; (3) temperature; (4) pH; (5) presence or absence of toxic materials; (6) pretreatment of sewage; (7) volumetric loading rate; and (8) quality and quantity of the filter film. These factors are discussed in detail by Heukelekian,[17] Hood,[8] Dreier,[18] and Walton.[4]

As pointed out previously, trickling filters are recognized as important tools in the secondary treatment of certain wastes. These include domestic sewage, certain industrial wastes and admixtures of the two. If this be the case, why shouldn't trickling filters also function to decontaminate wastes containing certain radio-isotopes?

Several authors have discussed the overall waste disposal problem and its implications both on and off atomic energy installations. Wolman and Gorman[19] in discussing the future of the atomic energy industry state: "The future growth of this new industry from the developmental stage to that of applied use of its products may well hinge on its ability to find increasingly effective and reasonable economical methods of disposal of its hazardous waste products." The complex problems of this new field -- radioactive waste disposal -- are discussed elsewhere.[20, 21, 22, 23, 24, 25, 26]

Ruchhoft[27] has outlined the possible use of biological treatment methods for treating contaminated wastes and gives some preliminary results from the use of the activated sludge process at Los Alamos. He also discusses the major differences between waste treatment as such today and its future component, radioactive waste treatment.

The activated sludge process, similar to the trickling filter process, is being investigated in the treatment of certain radioactive wastes at Los Alamos. This special use of this process is discussed at length by Newell.[28] The work at Los Alamos indicates that with a 23-hour aeration period, 90 to 95 per cent of tracer quantities of plutonium 239 can be removed from aqueous waste solutions.

In the present work carrier-free radioactive iodine ($I^{131}$) was selected as the isotope for investigation. This choice was made after carefully considering the following factors: (1) the economy; (2) availability; (3) general usage as to type and distribution; and (4) desirability for use in this type investigation. As to economy, $I^{131}$ is the cheapest available isotope at the present time -- $1.00 per millicurie (mc) obtained from the Operations Division, Oak Ridge National Laboratory (O.R.N.L.), Oak Ridge, Tennessee. $I^{131}$ is usually available or can be made so on short notice.

The most important reason for this choice lies in the extensive use of $I^{131}$ for medical therapy and research activities. $I^{131}$ is one of the four most frequently shipped isotopes, and these four isotopes constituted 75 per cent of the total radio-isotope shipments to June 30, 1949. Actually $I^{131}$ has the most widespread use of any isotope in the United States. Most of the wastes, from the treatment of patients and from research applications, are disposed of by discharge into sewer systems either prior to or subsequent to treatment.[29] This is not intended to mean, nor does it mean, that isotope users are promiscuously contaminating our sewerage systems and natural waters. However what it does imply is that, with its widespread use and nature of its use, $I^{131}$ is very apt to end up at a sewage treatment plant.

Several things are taken into consideration in the fourth factor -- desirability of use for this type study. $I^{131}$ has several strong beta ($\beta$-) particles and several weak gamma ($\gamma$) rays. The strong $\beta$'s make $I^{131}$ fairly easy to count which is a very desirable feature. The weak $\gamma$'s and complete absence of alpha ($\alpha$) particles are factors that tend to reduce certain specific radiation hazards.

After determining the characteristics of filter operation utilizing the B.O.D. test as a criterion and selecting the isotope ($I^{131}$) to be employed in this investigation, the next step was the spiking of settled sewage with a certain concentration of isotope and passing this spiked sewage through the filter columns. This was done and samples collected from various filter depths to determine the removal of activity and thus correlate dosage rate, $I^{131}$ removal and filter depth.

## DESCRIPTION OF EQUIPMENT

### Filters

Four of six experimental filter columns, previously designed, constructed and set up by the Waste Disposal Research Group, were used. These columns were set up in building 104B at O.R.N.L. The columns, constructed of lucite, are six feet in depth, with a two-inch internal diameter and filled with one-half inch to one inch broken stone. The filters are provided with sampling points at each one-foot increment of depth. The experimental trickling filters are shown in Figure 1. A close-up, indicating the prolific growth of slimes, is shown in Figure 2.

The filter medium used was quarry limestone obtained locally. The volume of voids varied from 45 to 50 per cent. Data for volume of voids calculation are included in Table I.

TABLE I

VOLUME OF VOIDS DATA

| Sample No. | Total Volume (ml) | Volume of Water to Fill Voids (ml) | Volume of Voids (%) |
|---|---|---|---|
| 1 | 3700 | 1645 | 44.5 |
| 2 | 2560 | 1277 | 50.0 |

The feed tank may be seen in the lower left hand corner of Figure 1. It is a 25-gallon galvanized garbage can. The influent lines may be seen leading out of the feed tank and also just behind the filter columns. These tubes have a 1/8-inch internal diameter and are

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Figure 1. General View of Filters

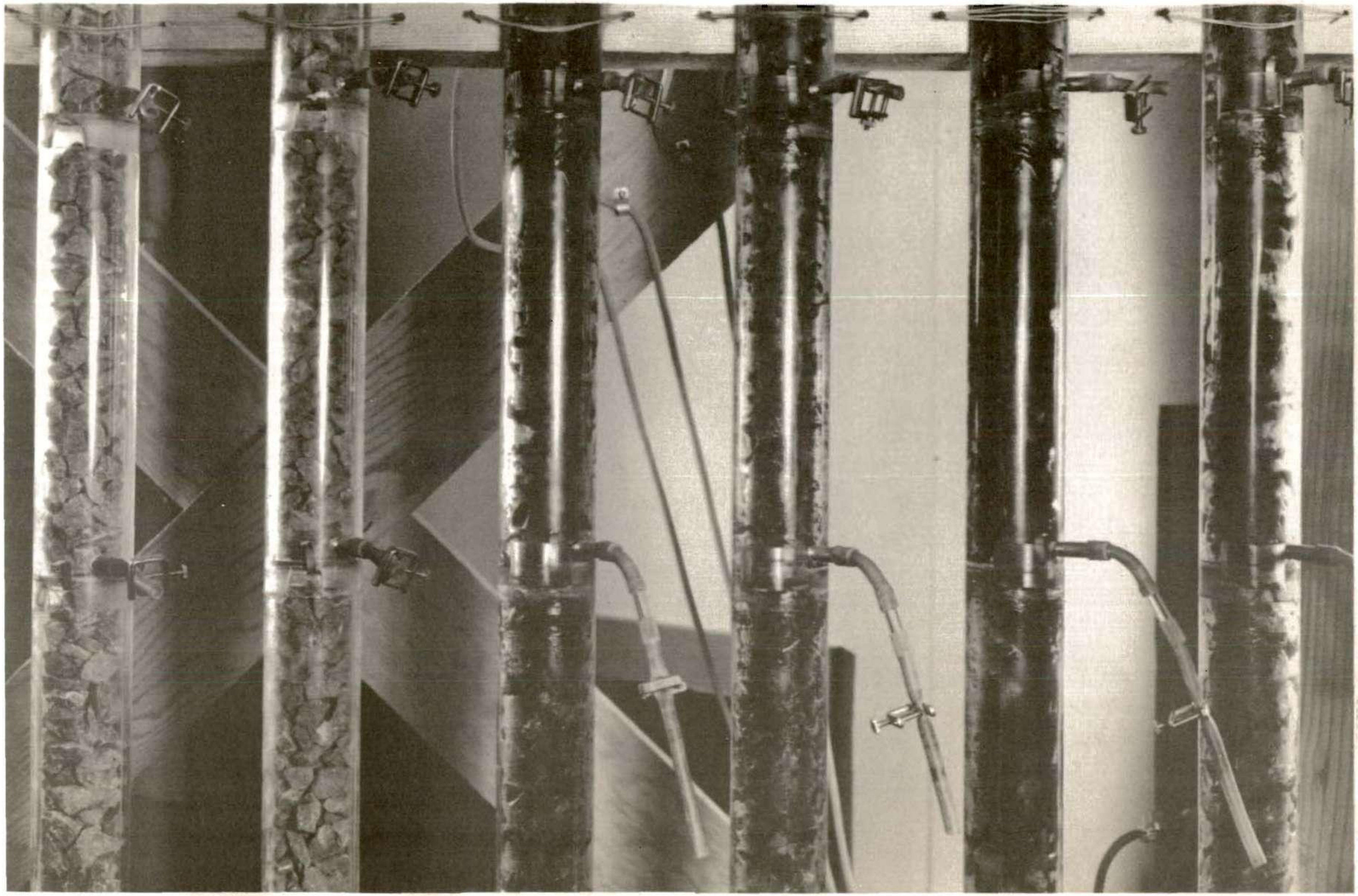

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Figure 2. Close-up View of Filter Columns

made of gum rubber. The first carboy on the left was used as the feed tank when using spiked sewage. The effluent lines may be seen extending into the four containers at the lower right.

The Harvard pump (a positive displacement pump) used for circulation is located on the platform seen at the bottom of Figure 1. It was used to pump the influent to the top of the filter columns. The sewage passed through the filters by gravity.

The valves, which are located at one-foot increments of depth, may be seen in Figure 1. A close-up is seen in Figure 2. They consist of perforated plates, one stationary and the other movable by means of a small lever projecting through a slot in the filter wall. Leakage was evident from most of these slotted openings, so small wells were constructed of lucite and glued around each valve opening (see Figure 2). These wells were installed prior to using $I^{131}$ and successfully prevented any leakage. All filter joints were glued as a preventative measure against possible leakage and thus contamination with $I^{131}$.

Two Taylor maximum and minimum thermometers may be seen in the upper left hand corner of Figure 1. These were used to record maximum and minimum air temperatures daily. The radiation signs are used for "outside" personnel and also for personal reminder of the ever-present danger when using radioactive materials. Radiological safety procedures will not be discussed but may be found elsewhere.[30, 31]

## Biochemical Oxygen Demand Equipment

Dilution water was aerated by compressed air, which had been filtered through two inches of water. The aeration containers were made from five-gallon carboys, fitted with two-hole No. 12 stoppers with air intake line and dust-protected breather tube.

Dilutions were mixed in a two-liter graduate using a perforated lucite plate with a 1/4-inch diameter brass rod handle. (This stirring rod had another perforated lucite disk at the opposite end, which was of such a size as to be suitable for mixing dilutions in a one-liter graduate).

The incubator used is a commercial type, being a remodeled refrigerator equipped with thermostatic control. The incubation temperature was checked daily and was always found to be 20 $\pm$ 0.5°C. This incubator was defrosted approximately once a month.

Counting Equipment

The counting dishes and drying lamps may be seen in Figure 3. The counting dishes were made of aluminum at the Health Physics Machine Shop at O.R.N.L. Those used will hold a maximum of 10 milliliters (ml) of solution. The drying lamps are 375-watt infra-red bulbs which are available commercially.

In Figure 4 is seen the timer, pig and scaler used for counting samples in this investigation. The timer was manufactured by Precision Scientific Company and records in seconds and tenths of seconds. It operates on 115 volts, 60 cycles and 5 watts. The pig is A.E.C.-O.R.N.L. No. X-43989. The data for the scaler includes G-M scaler, Serial No. 4910, A.E.C. Model CGM-3B, manufactured for the Atomic Energy Commission (A.E.C.) under Contract No. AT-40-1-GE N 611 by El-Tronics, Inc., Philadelphia, Pennsylvania.

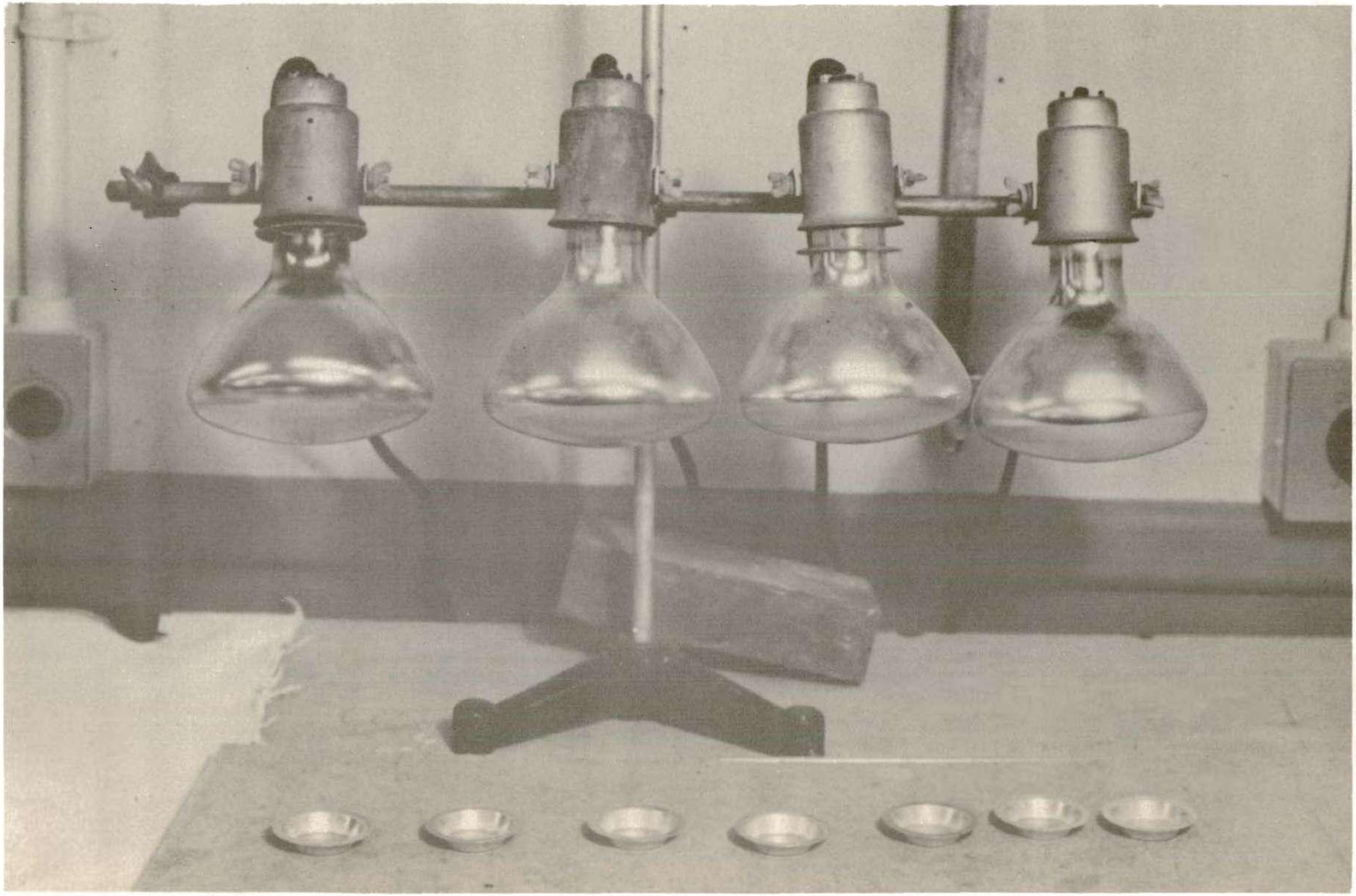

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Figure 3. Sample Drying Arrangement

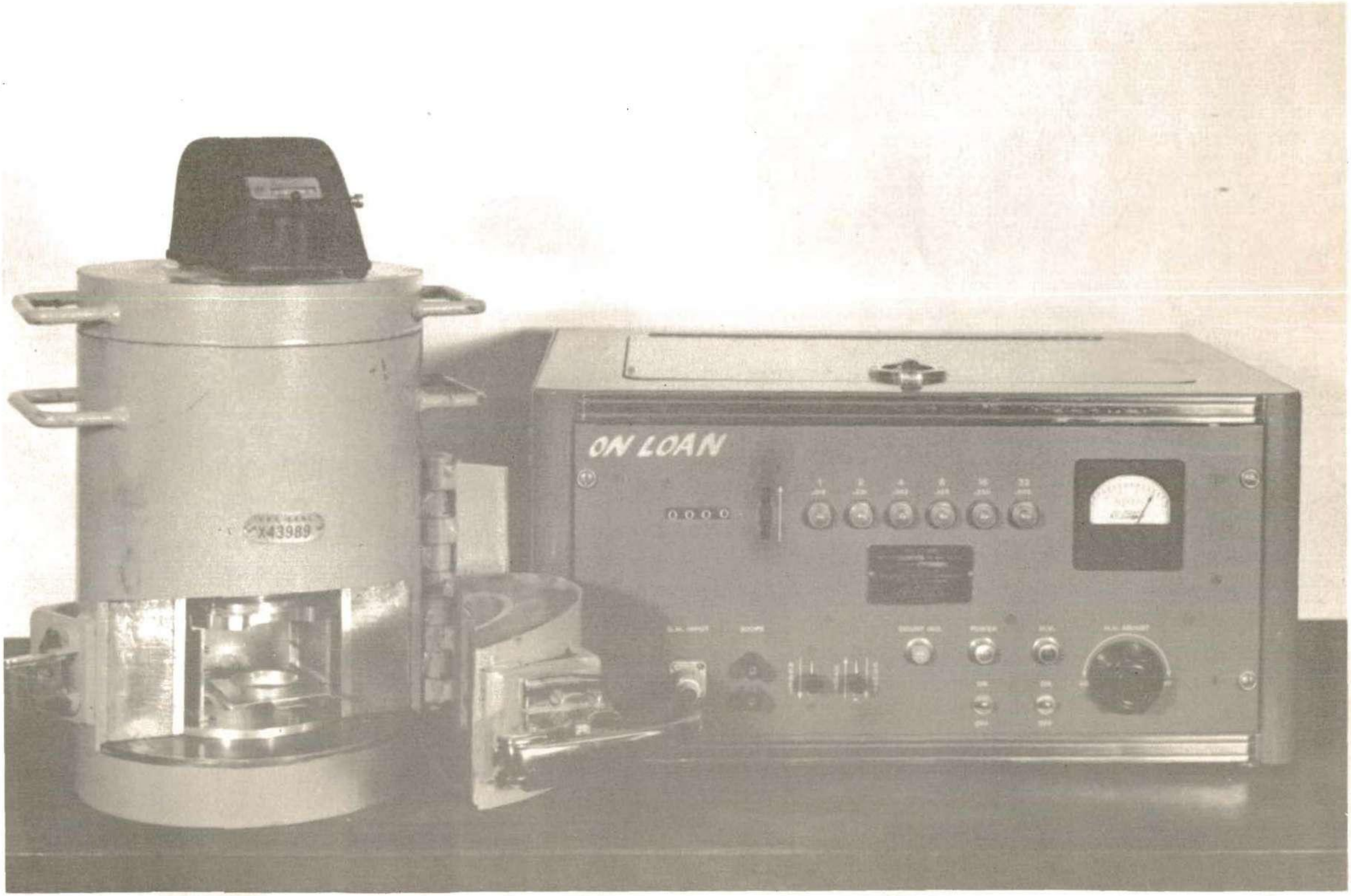


Figure 4. Counting Equipment

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The sample holder may be seen inside the pig, with a dish in the No. 4 shelf position. Shelf No. 2 was used exclusively in this study. It is evident that the pig has heavy lead walls to reduce background.

The scaler circuit was operated normally at 1.2 kilovolts. For this reason the control board has two power switches, one marked "power" and the other "H.V." (high voltage). The scaler records in units of 64 (that is, one scale reading is equivalent to 64 registered counts). The lights at the top of the panel give combinations of counts from 1 to 63. The large knurled knob at top left is used to clear the scale readings. The reset switch is for clearing lights at the end of a counting period after first recording the registered counts. The count switch is for starting and stopping counts from being received and is connected to and used to automatically start and stop the timer in unison.

Before counts are made, the power and H.V. switches are thrown. (It takes a few seconds for the operating voltage of 1.2 kilovolts to be reached). All dials and lights are cleared both from the control panel and timer before the instrument is ready to operate. The sample is then placed in the sample holder, the door closed and the count switch pushed to the "on" position. At the end of a counting period, the counts and counting time are recorded.

# PROCEDURE

## Sampling Technique

Raw sewage was collected from a four-foot manhole in the O.R.N.L. area using a stainless steel container and a rope. Two five-gallon carboys were usually filled at each sampling period. The temperature of the raw sewage was taken and recorded. The raw sewage was allowed to stand in the carboys under quiescent conditions for one hour, at which time the supernatant was siphoned into the feed solution tank. A five-gallon carboy was used for the mixing and feed tank when using the radioactive isotope.

Influent and effluent samples were collected into either Erlenmeyer flasks or graduates. The collection time (time taken for sample collection) and volume, as well as the time of collection (time after isotope addition to filters, which is taken as "zero" time), were recorded.

## Biochemical Oxygen Demand Technique

Samples for B.O.D. analysis were immediately set up after collection. All reagents and the dilution water were prepared according to Standard Methods for the Examination of Water and Sewage.[32] The sodium azide modification of the Winkler method was used in all D.O. determinations.

Various dilutions were made by pipetting (all pipetting was done using a rubber bulb "vacuum" technique) the required quantities of sewage into a two-liter graduate which was previously filled to about the 700-ml mark with dilution water. The dilution water was siphoned into the graduate with a minimum of aeration. After sewage addition (pipetted with the tip of the pipette under water surface), the total volume was brought up to the 1,500 ml mark by the addition of more dilution water. The mixture was then stirred with a plunger type stirring rod. Next, four B.O.D. bottles (250-300 ml) were filled with the mixture by a siphon after 50 to 100 ml had been wasted. Two bottles were then incubated (for five days at 20°C), and the D.O. of the other two samples was determined. This procedure was adhered to rigorously and two duplicate dilutions were always run.

Starch indicator solution was prepared approximately twice a week, preserved (using 1.25 grams of salicylic acid per liter) and refrigerated while not in use. Thiosulfate solutions were made up from a stock solution (O.I.N.) and then preserved using 0.4 grams of NaOH per liter. Thiosulfate solutions were checked for normality using a 0.025 N bi-iodate standard. Blanks were run with each set of daily samples and also when dilution water was changed. However, dilution waters from two containers were never mixed.

## Counting Techniques

Carrier-free $I^{131}$ was obtained from the Operations Division, O.R.N.L. The quantity received at any one time was 2 to 3 mc. This was diluted to approximately 200 ml and served as a stock solution. Three 1-ml portions of the stock solution were counted, so the amount to be added to eight liters of settled sewage could be ascertained. The eight liters of feed solution were to have a concentration of approximately 1,000 counts per minute per milliliter (c/m/ml).

Duplicate or triplicate samples of the mixed influent feed solution were taken for counting prior to the start of a run.

All samples were "dry" counted. Liquid samples varied in volume from 1 to 10 ml. After collection, representative samples of the mixed effluent were pipetted from the graduates and placed in aluminum countint dishes. Duplicate samples were always run. The dishes containing the samples were then placed under infra-red lamps at approximately a one-foot distance (see Figure 3 for a view of the dishes and the arrangement for drying samples). This distance between sample and lights was thought to be close enough for rapid drying and at the same time far enough away to prevent volatilization of samples. The dishes (samples) were then counted on the second shelf of the sample holder, using a Geiger-Muller (G-M) end window counter. The counting time (actual time counts are being received), registered counts, background and time of counting (as related to "zero" time) were recorded.

# TECHNIQUES OF STUDY

## Introduction and Collection of Raw Sewage

Considerable time was spent in ripening the filters. This is the process whereby the stones comprising the filter bed become the home of a heterogeneous group of sewage-supported organisms. This biological population consists of varied organisms but is composed chiefly of bacteria. When trickling filters are operating normally, this population forms a balanced community whose well-being is essential to the treatment of wastes by this process. Maturing of the filters was accomplished by passing settled sewage through them for a period of several weeks.

In this preliminary phase of operations, some time was spent in adapting techniques suitable for this study. Considerable experience was also gained in running B.O.D. determinations involving a wide range of dilutions.

At first, it seemed desirable to obtain settled sewage from an existing sewage facility. This was arranged and samples were collected on Monday, Wednesday, and Friday of each week from the East Village Sewage Treatment Plant, Oak Ridge, Tennessee. The sewage obtained was thought to be too weak for this work, having a B.O.D. in the range of 30 to 70 parts per million (ppm).

Next, samples of settled sewage were collected from the West Village Sewage Treatment Plant, Oak Ridge, Tennessee, but this sewage also proved to be very dilute (same B.O.D. range as East Village sewage); therefore another source was sought. Since some data were available on

O.R.N.L. sewage, it was thought practical to obtain raw sewage in the Laboratory area and settle it in the laboratory.

These initial attempts to find a source of good settled sewage served the two following very useful purposes: (1) valuable experience in laboratory procedures was gained and (2) use of the sewage was made in maturing the filters.

Permission was granted to obtain raw sewage from a shallow (four-foot) manhole in the 900 area of O.R.N.L. The available data indicated that a period of maximum flow and strength occurs at approximately nine o'clock A.M. Preliminary tests indicated the B.O.D. of the settled sewage was somewhat higher than that of the previously used sewages, having a general range of 60 to 100 ppm. Therefore, it was decided to use this source of sewage and to collect it at approximately nine o'clock on the morning of its use.

This sewage is on the dilute side, but rather than fortify it with some nutrient material it was thought best to use it in its natural state. It should be mentioned that this sewage is similar to normal domestic sewage and probably differs only in freshness and strength. This is due to the short time in the sewer system subsequent to initial discharge. At times there were wastes other than domestic sewage flowing in the sewer system, as evidenced by appearance, odor, and at one time by an unusually high B.O.D. value. When other wastes were evident, samples were collected at a slightly later time in order to use as normal a sewage as possible.

A settling time of one hour was used, which seems adequate if one takes into consideration the quiescent conditions obtainable in the laboratory, as compared to the standard time of two hours used in general practice for the design of primary settling tanks.

The procedure finally evolved was to collect sewage at approximately nine o'clock on the morning of its use and to settle this raw sewage for one hour in five-liter carboys. Actual collection of the samples was accomplished by lowering a two-liter stainless steel container, fastened to a rope, down into the channel flow and then pouring its contents into the carboy. Usually, two five-gallon carboys were filled. At the time of collection, a thermometer was suspended in a carboy and the temperature recorded in degrees centigrade, after time for temperature adjustment. This temperature is referred to as the raw sewage temperature.

This sampling procedure was followed throughout this study with samples being collected on "run" days or on an alternate day schedule Monday through Friday. On week ends and days sewage was not collected, the filter effluents were recirculated through the filters.

Filter Influent Sampling

Filter influent samples were, in general, taken from the feed solution tank and also from the top of each filter column by collection into Erlenmeyer flasks. The samples for B.O.D. determination were taken after mixing of the settled sewage to suspend any settled solids. Samples for B.O.D. determination were not taken at the tops of the filters as it was thought that tank samples would yield the same B.O.D. values. It was thought that tank samples would be sufficient since there were definite limitations on time and equipment. Some B.O.D. reduction did take place while the sewage passed through the influent lines. This was due to slime growths in the lines and eventually led to control measures being taken. While some B.O.D. reduction probably did take place at all times in the influent lines, it was thought to be of a very low order of magnitude. (For a discussion of this problem, see the section entitled "Problems and Special Investigations").

When samples were taken of the spiked influent, they were taken from the feed tank (five-gallon carboy) and also from the top of each filter column. The feed solution was thoroughly mixed before sampling except when samples were taken to determine the effect of additional sedimentation on the feed solution.

Spiked sewage samples were taken at the top of each filter column for counting purposes by collection in small graduates held under the discharge end of the influent line. The quantity and duration of collection were recorded.

## Filter Effluent Sampling

Effluent samples were collected from each filter at one of six sampling points, located at one-foot depth intervals. Difficulty was encountered in collecting samples from certain depths due to faulty valves. This was the case at the four-foot depth of filters No. 2 and 4 and also at the five-foot depth of filter No. 4. No samples were taken from these particular sampling points. Vertical leakage of several other valves resulted in lengthy collection times and also necessitated two containers for volume determination, one for sample volume at the point of collection and the other at the six-foot depth (final filter effluent).

Samples were collected either in graduates or Erlenmeyer flasks. When effluent B.O.D. samples were collected, Erlenmeyer flasks were used. Samples were collected over a definite period of time, and the volume and time of flow were recorded. The dosage rate could be calculated from these data but it is thought that a much better value for the dosage rate could be obtained by computing the average rate from the total volume of sewage passed through the filters and the total time of flow.

Dosage rates were calculated in the same manner when using spiked sewage. Effluent samples were taken more frequently and at a larger number of sampling points. They were collected directly into small graduates.

It should be pointed out that the flow rate and consequently the dosage rate could not be controlled as closely as desired. This difficulty was due to the nature of the substrate (domestic sewage) and also to the extremely low flow rates involved -- 2.62 milliliters per minute (ml/m) for a dosage rate of 2 million gallons per acre per day (mgad). After settling, the supernatant still contains suspended solids which tend to clog lines when using such low flow rates. Another aspect of this problem is the growth of slimes in the feed lines and their periodic sloughing. These factors contribute to erratic flow rates and require constant supervision. Thus, only data of dosage rates within $\pm$ 15 per cent of the desired dosage rate are included in the first phase (B.O.D. phase) of this work.

## Biochemical Oxygen Demand Test

The B.O.D. test was chosen as the best single criterion for filter operation due to its paramount usage in the sanitary engineering field. A brief discussion of this test has previously been presented in the "Introduction" to this paper.

Dilution water used in these tests was made by using the existing distilled water, after first determining its quality in respect to the presence of copper. (See section entitled "Problems and Special Investigations").

Two dilutions were run in duplicate for all B.O.D. tests. These dilutions were chosen in view of obtaining the recommended 40 to 70 per cent depletion of dissolved oxygen. Occasionally, only one blank was run. This occurred when a given bottle of dilution water was almost used up.

The standard incubation time of five days at 20°C was used. In all cases, the actual incubation period was five days ± four hours. With good temperature control during incubation (20 ± 0.5°C) and the techniques used, it is thought that reliable results were obtained.

## Counting of Samples

All counts were made on dried samples. Samples were first dried, using infra-red lamps, and then counted on the second shelf of a particular G-M end window counter. The second shelf of this instrument was always used for counting samples, since this, for all practical purposes, eliminated the need for geometry correction. (For a discussion of geometry and other material discussed here, the reader is referred to Lapp and Andrews).[33] This was a relative study (condition of influent versus condition of effluent) rather than an absolute one making this simplification possible.

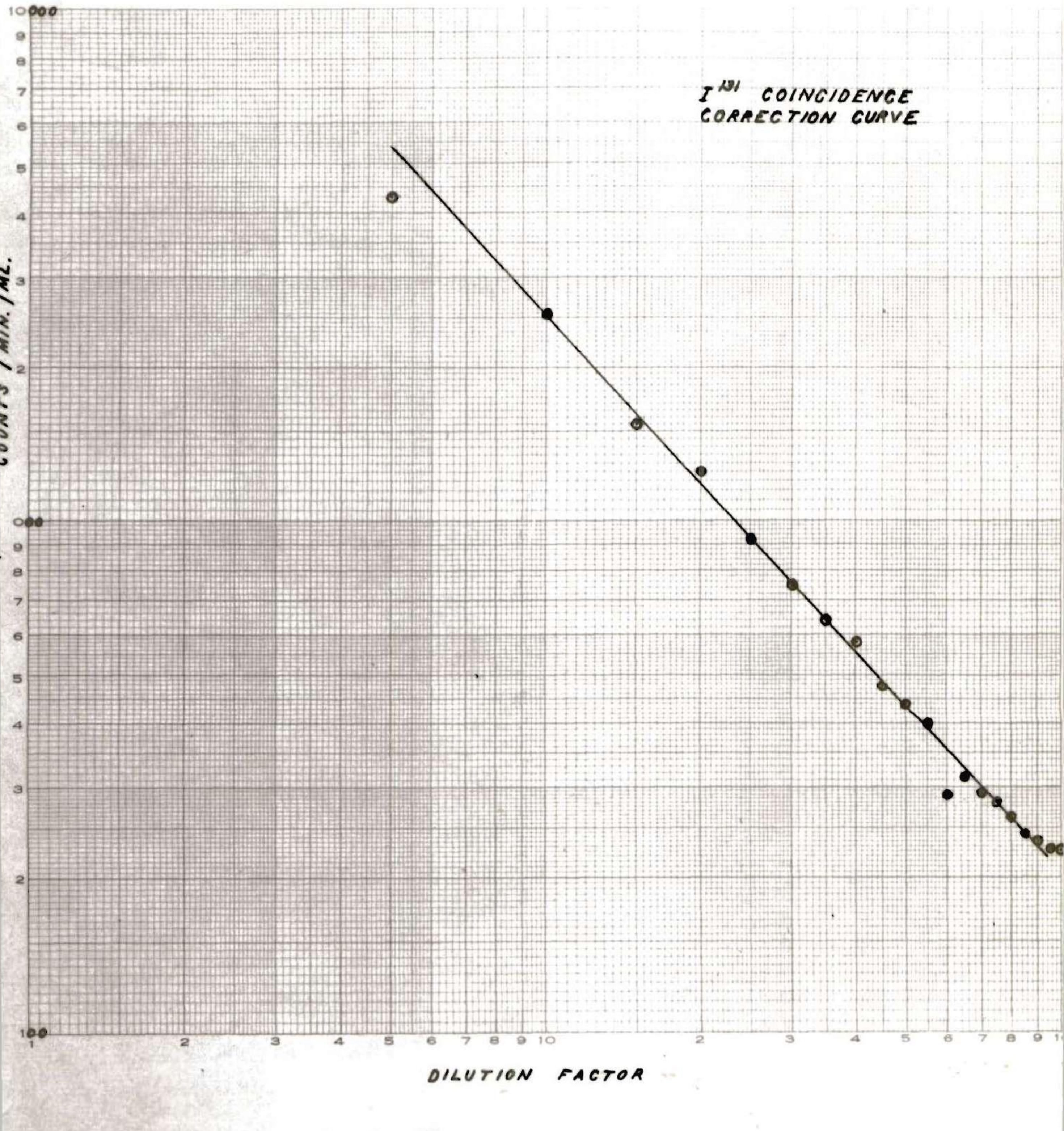
Background (the radioactivity caused by cosmic radiation and radiations from radioactive materials in the vicinity) is extremely important when working with samples having low counts. In this study, the background varied from 25 to 35 counts per minute (C/M). A background count was taken about every two to four hours and was for a 10-minute period. Since radioactive disintegration is a statistical process, enough counts must be registered to give statistically good results.

Samples were normally counted to the nearest minute after 100 scalers had been registered (100 x 64 counts) or for five minutes, whichever occurred first. It is thought that this procedure resulted in reliable results.

Other factors normally considered are self-absorption, dead-time loss and coincidence loss. In this study no correction was made for self-absorption (the absorption of radiations by material emitting them plus inert solids). Dead-time loss is an actual loss of counts due to the resolving time of the instrument used (the time it takes the counter to receive a count and be ready to receive the next count). This correction for dead time is usually small when working with materials with low activity and was disregarded in this study. Coincidence loss (the loss due to the emanation of several radioactive particles which is recorded as a single count) was negligible in this study since low activity samples were always counted.

In sample counting the time of counting is important, especially when working with short half-lived isotopes. Since $I^{131}$ (with an eight day half life) was used, decay corrections were always made. Half life refers to the time it takes one-half of the material originally present to disintegrate. Thus, if we had $1 \times 10^8$ counts of $I^{131}$ in a sample, in eight days we would have $5 \times 10^7$ counts, etc. Half life may be determined for substances such as $I^{131}$ by taking a given sample and counting it under the same conditions daily. The results are plotted on semi-log paper (counts versus time), and the half life is found by observing the time for 50 per cent of the original counts to be counted. (This is a very simplified explanation, since other factors such as sample preparation, statistics, etc., should be considered). Examples of coincidence-loss curves, decay curves, and decay-correction curves may be seen by referring to Figures 5, 6, and 7, respectively. For further information on units and general information the reader is referred to Evans,[34] Glasstone,[35] Sullivan,[36] and Friedlander and Kennedy.[37]

FIGURE 5



$I^{131}$ COINCIDENCE CORRECTION CURVE
COUNTS / MIN. / ML.
DILUTION FACTOR
10000
1000
100
1
2
3
4
5
6
7
8
9
10

FIGURES 6 AND 7

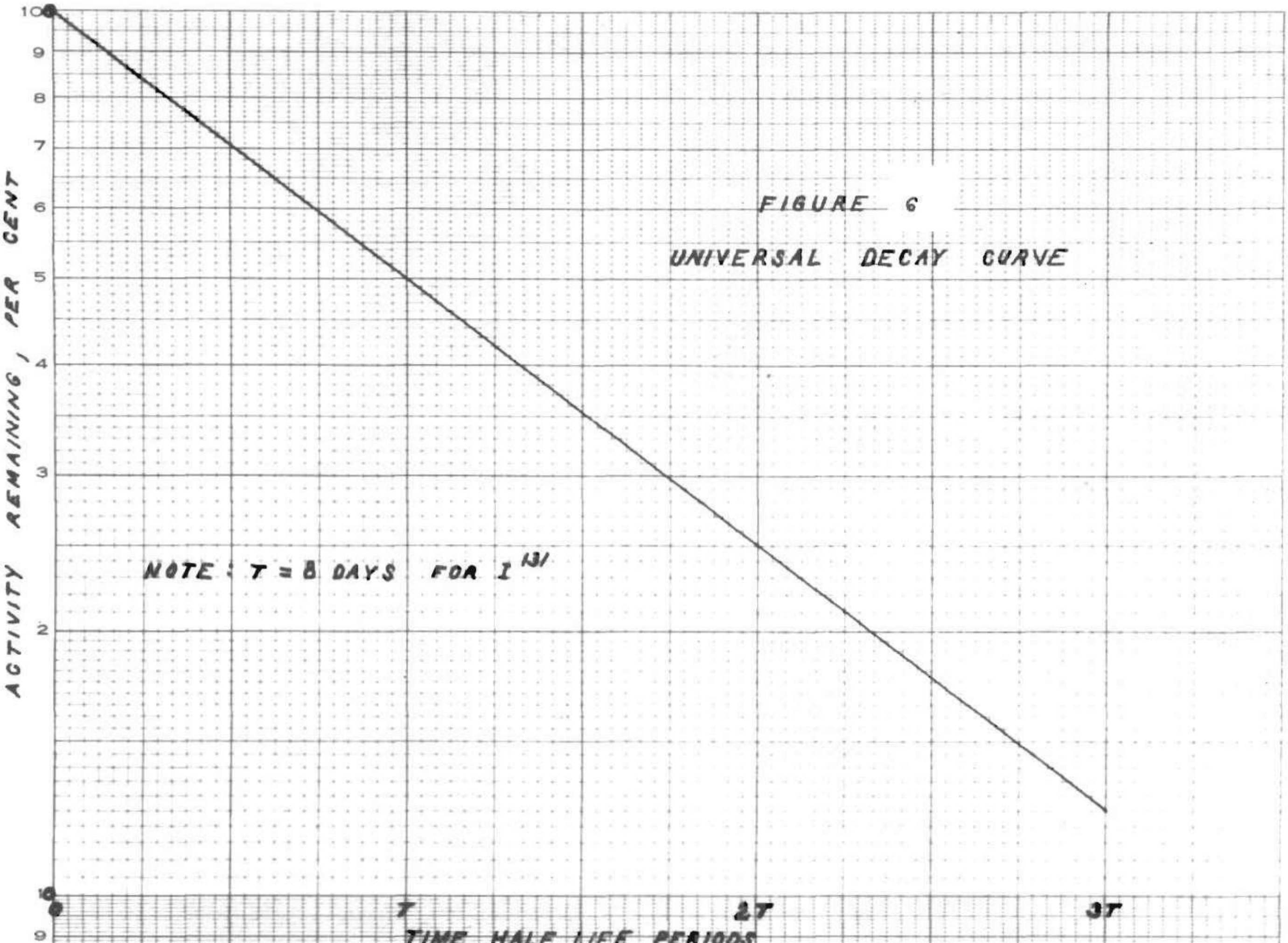



FIGURE 6
UNIVERSAL DECAY CURVE

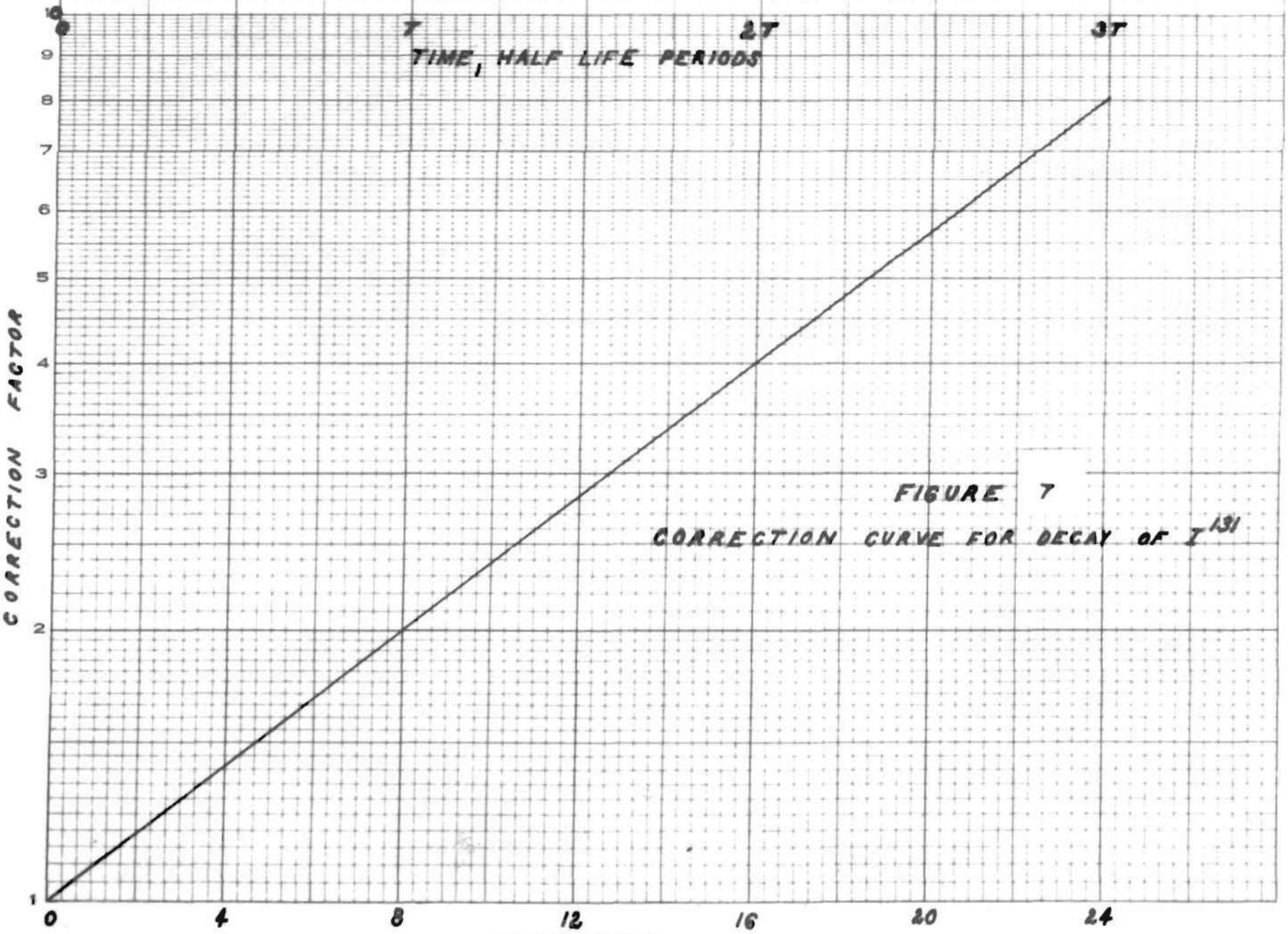



FIGURE 7
CORRECTION CURVE FOR DECAY OF $I^{131}$

## RESULTS AND DISCUSSION OF RESULTS

### Preliminary Phase of Work -- Biochemical Oxygen Demand Results

Table II summarizes the results of 31 runs. These data are arranged on the basis of dosage rate and filter depth rather than chronologically (run numbers) and indicate the per cent B.O.D. remaining at various filter depths for different dosage rates. Each B.O.D. value as presented actually consists of two duplicate dilutions. The results thus shown in the last four columns are average values.

In Table III the data from the 31 runs included in Table II are presented as mean values. These are arranged in groups according to depth of filter and dosage rate. They indicate that B.O.D. removals of 92, 85, and 76 per cent were obtained at dosage rates of 2, 4, and 6 mgad, respectively. These relationships may best be seen in Figure 8, where the B.O.D. remaining and depth of filter (values taken from Table III) are plotted. This relationship is indicated for three dosage rates, namely 2, 4, and 6 mgad. Each of these plotted points represents the mean of four or more values.

Table IV is an example of the individual results on the 31 runs used for Tables II and III and Figure 8. The nomenclature used for the numbering of samples is as follows: (a) the first number refers to the date of titration; (b) DW is for dilution water, I for influent, and E for effluent; (c) the first number of the superscript indicates the filter sampled, and the second number refers to the depth (no second number means six-foot depth); and (d) the subscript indicates the dilution, expressed in per cent.

TABLE II

SUMMARY RESULTS OF BIOCHEMICAL OXYGEN DEMAND (B.O.D.) TESTS

| Run No. | Date of Run | Filter No. | Sampling Depth (ft) | Dosage Rate (mgad) | Influent B.O.D. (ppm) | Effluent B.O.D. (ppm) | B.O.D. Removed (%) | B.O.D. Remaining (%) |
|---|---|---|---|---|---|---|---|---|
| 3 | 8/14/50 | 4 | 3 | 2.02 | 95.1 | 37.0 | 61.1 | 38.9 |
| 10 | 8/24/50 | 2 | 3 | 1.85 | 51.4 | 7.2 | 86.0 | 14.0 |
| 11 | 8/24/50 | 3 | 3 | 2.26 | 51.4 | 19.0 | 75.3 | 24.7 |
| 12 | 8/24/50 | 4 | 3 | 2.05 | 51.4 | 14.9 | 71.0 | 29.0 |
| 20 | 9/13/50 | 2 | 3 | 1.98 | 64.0 | 7.7 | 88.0 | 12.0 |
| 26 | 9/20/50 | 3 | 3 | 1.92 | 47.3 | 25.0 | 47.1 | 52.9 |
| 4 | 8/16/50 | 2 | 6 | 1.93 | 79.5 | 10.5 | 86.8 | 13.2 |
| 9 | 8/24/50 | 1 | 6 | 2.27 | 51.4 | 5.7 | 88.9 | 11.1 |
| 22 | 9/14/50 | 2 | 6 | 1.89 | 65.3 | 2.3 | 96.5 | 3.5 |
| 25 | 9/20/50 | 2 | 6 | 1.92 | 47.3 | 2.1 | 95.6 | 4.4 |
| 27 | 9/20/50 | 4 | 6 | 1.95 | 47.3 | 3.3 | 93.0 | 7.0 |
| 1 | 8/7/50 | 3 | 3 | 4.18 | 92.7 | 35.2 | 62.0 | 38.0 |
| 2 | 8/11/50 | 1 | 3 | 3.95 | 50.2 | 23.0 | 54.2 | 45.2 |
| 8 | 8/18/50 | 3 | 3 | 3.94 | 220 | 86.5 | 60.7 | 39.3 |
| 15 | 8/25/50 | 4 | 3 | 3.66 | 77.5 | 25.9 | 66.6 | 33.4 |
| 19 | 9/1/50 | 3 | 3 | 3.75 | 82.0 | 32.9 | 61.1 | 38.9 |
| 14 | 8/25/50 | 2 | 6 | 4.07 | 77.5 | 6.8 | 91.2 | 8.8 |
| 17 | 8/31/50 | 3 | 6 | 4.18 | 96.5 | 15.0 | 84.5 | 15.5 |
| 18 | 9/1/50 | 1 | 6 | 3.91 | 82.0 | 12.6 | 84.6 | 15.4 |
| 21 | 9/13/50 | 4 | 6 | 3.57 | 64.0 | 8.9 | 86.1 | 13.9 |
| 23 | 9/14/50 | 3 | 6 | 4.41 | 65.3 | 12.6 | 80.7 | 19.3 |
| 16 | 8/31/50 | 1 | 3 | 6.00 | 96.5 | 51.5 | 46.6 | 53.4 |
| 30 | 9/21/50 | 2 | 3 | 5.78 | 90.1 | 47.9 | 46.8 | 53.2 |
| 31 | 9/21/50 | 4 | 3 | 6.07 | 90.1 | 42.1 | 53.3 | 46.2 |
| 34 | 9/22/50 | 2 | 3 | 6.71 | 86.3 | 41.0 | 52.5 | 47.5 |
| 13 | 8/25/50 | 1 | 6 | 6.08 | 77.5 | 12.9 | 83.4 | 16.6 |
| 24 | 9/14/50 | 4 | 6 | 6.00 | 65.3 | 11.8 | 81.9 | 18.1 |
| 28 | 9/21/50 | 2 | 6 | 5.52 | 90.1 | 24.5 | 72.8 | 23.2 |
| 29 | 9/21/50 | 4 | 6 | 5.54 | 90.1 | 29.8 | 66.9 | 33.1 |
| 32 | 9/22/50 | 2 | 6 | 6.34 | 86.3 | 21.9 | 74.6 | 25.4 |
| 33 | 9/22/50 | 4 | 6 | 6.66 | 86.3 | 17.9 | 79.3 | 20.7 |

TABLE III

B.O.D. REMOVAL AS A FUNCTION OF DEPTH AND DOSAGE RATE

| Part | Sampling Depth (ft) | Dosage Rate (mgad) | Influent B.O.D. (ppm) | Effluent B.O.D. (ppm) | B.O.D. Removed (%) | B.O.D. Remaining (%) |
|---|---|---|---|---|---|---|
| A | 3 | 2.02 | 60.1 | 18.3 | 71.4 | 28.6 |
| B | 6 | 1.99 | 58.2 | 4.8 | 92.2 | 7.8 |
| C | 3 | 3.90 | 64.9 | 40.7 | 60.9 | 39.1 |
| D | 6 | 4.03 | 77.1 | 11.2 | 85.4 | 14.6 |
| E | 3 | 6.14 | 90.8 | 45.9 | 49.8 | 50.2 |
| F | 6 | 6.02 | 82.6 | 19.8 | 76.5 | 23.5 |

FIGURE 8

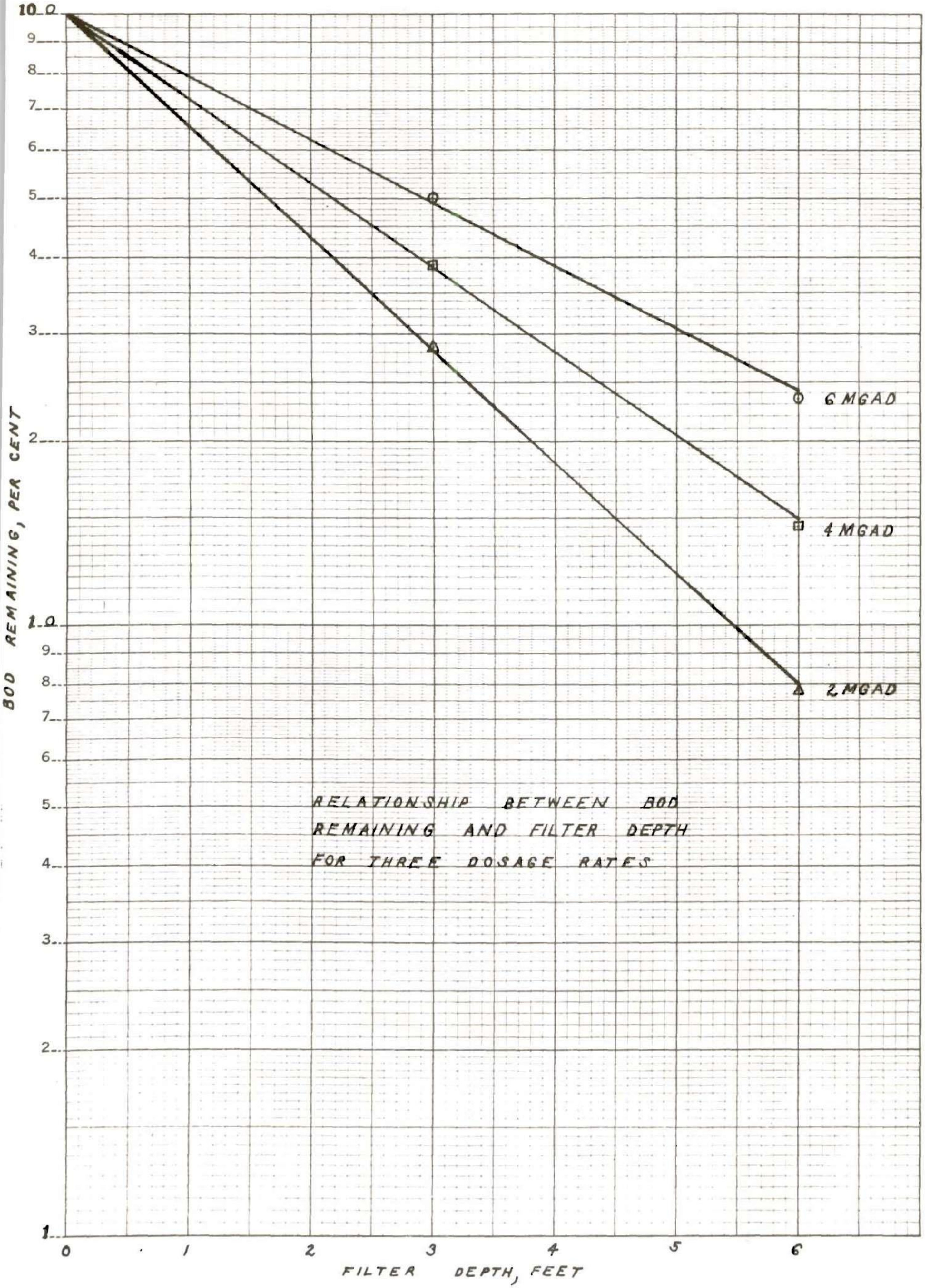

10.0
9
8
7
6
5
4
3
2
1.0
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
BOD REMAINING, PER CENT
FILTER DEPTH, FEET
6 MGAD
4 MGAD
2 MGAD
RELATIONSHIP BETWEEN BOD
REMAINING AND FILTER DEPTH
FOR THREE DOSAGE RATES

TABLE IV

INDIVIDUAL RESULTS OF BIOCHEMICAL OXYGEN DEMAND (B.O.D.) TESTS

Run No: 1
Date: 8/7/50
Time of Sewage
Collection: 9:00-9:30 A.M.

Sewage Settled for 1 Hour
Raw Sewage Temperature: 24.6°C
Dosage Rate: 4.18 mgad

| Sample No. | Titration Results: Burette Readings (ml) | Titration Results: $Na_2S_2O_3$ Used (ml) | Average $Na_2S_2O_3$ Used (ml) | Average Dissolved Oxygen (ppm) | B.O.D. (ppm) |
|---|---|---|---|---|---|
| 7DW | 46.00-38.00 | 8.00 | 8.00 | 8.13 | |
| 12DW | 7.91-0.04 | 7.87 | 7.87 | 8.00 | |
| $7I_5$ | 7.40-0.01 | 7.39 | 7.34 | 7.46 | 97.4 |
| $7I_5$ | 14.69-7.40 | 7.29 | | | |
| $12I_5$ | 10.50-7.90 | 2.60 | 2.55 | 2.59 | |
| $12I_5$ | 13.00-10.50 | 2.50 | | | |
| $7I_{6.67}$ | 22.03-14.68 | 7.35 | 7.39 | 7.51 | 88.0 |
| $7I_{6.67}$ | 29.46-22.03 | 7.43 | | | |
| $12I_{6.67}$ | 14.59-12.99 | 1.60 | 1.61 | 1.64 | |
| $12I_{6.67}$ | 16.20-14.59 | 1.61 | | | |
| $7E^{3-3}_{6.67}$ | 37.20-29.46 | 7.74 | 7.77 | 7.89 | 35.7 |
| $7E^{3-3}_{6.67}$ | 45.00-37.20 | 7.80 | | | |
| $12E^{3-3}_{6.67}$ | 41.05-35.70 | 5.35 | 5.42 | 5.51 | |
| $12E^{3-3}_{6.67}$ | 46.55-41.05 | 5.50 | | | |
| $7E^{3-3}_{10}$ | 7.69-0.00 | 7.69 | 7.69 | 7.81 | 34.6 |
| $7E^{3-3}_{10}$ | 15.37-7.69 | 7.68 | | | |
| $12E^{3-3}_{10}$ | 41.73-37.41 | 4.32 | 4.28 | 4.35 | |
| $12E^{3-3}_{10}$ | 45.98-41.73 | 4.25 | | | |

Under the conditions existent at our laboratory and in accordance with the techniques used, the data in Figure 8 indicate the results are in good agreement with Velz's "Basic Law for Biological Beds."[38] This law is similar to the familiar biological oxidation law -- namely, a monomolecular reaction. The rate of extraction of organic material per unit interval of depth of biological bed is proportional to the remaining organic material measured in terms of its removability. These data also indicate that the laboratory trickling filters used in this study are comparable in B.O.D. removal to those in general use in the United States today, as indicated by the data given in Table V. It should be pointed out that strict application of Velz's law could not be made due to the limited number of filter depths sampled.

The data presented in Table II show the variability in results when dealing with biological populations. These variations are inherent in such work and are mainly due to environmental conditions such as available food supply, pH, temperature, and presence or absence of toxic materials. Also, in this particular study, it should be pointed out that the flow rate could not be controlled as closely as desired. This difficulty is due to the nature of the substrate -- domestic sewage -- and also to the extremely low flow rates involved (2.62 ml/m for a dosage rate of two mgad).

The data contained in Tables VI through VIII for runs 5, 6, and 7, respectively, indicate the effect of slime growths in the influent lines. In these runs, B.O.D. removal appears to be independent of dosage rate and filter depth. As an example, run 5 and run 6 indicate approximately the same B.O.D. removal; yet run 5 is on a final effluent (six-foot depth) sample, and run 6 is on a three-foot depth sample. Also, equal B.O.D. removals are indicated in runs 6 and 7, and while both are three-foot depth samples the dosage rates are 6 and 2 mgad, respectively. All three runs indicate a false B.O.D. removal of approximately 85 per cent. The correct values (taken from Figure 8) should be approximately 75, 50, and 70 per cent for runs 5, 6, and 7, respectively.

The growth of slimes was controlled to a large extent by the periodic chlorination of all feed lines. This prevented excessive B.O.D. reduction while the sewage passed through the influent lines and also tended to minimize the problem of flow rate and thus dosage rate control. For a complete discussion of influent line slime growths see the section entitled "Problems and Special Investigations."

## Second Phase of Work -- Spiked Sewage Results

In the preliminary phase of this investigation, three dosage rates were used -- namely, 2, 4, and 6 mgad. For this latter phase, involving radioactive $I^{131}$, only one dosage rate (2 mgad) was investigated so that more complete results would be available at this particular dosage rate, rather than meager data on several dosage rates.

An example of the individual results for the 15 runs employing spiked sewage is presented in Tables IX and X. The nomenclature used for numbering samples in these tables is as follows: (a) the first number is for run numbers; (b) lower case letters refer to order of sampling and $I_o$ to tank sample; (c) the second number indicates sampling depth; and (d) the third number refers to filter number.

In Figures 9 through 17 are plotted the individual results of 15 runs using sewage spiked with approximately 1,000 c/m/ml of $I^{131}$.

TABLE V

EFFICIENCIES AND DOSAGE RATES OF
STANDARD RATE TRICKLING FILTERS

| Author | Results: Efficiency in B.O.D. Removed (%) | Results: Dosage Rate (mgad) |
|---|---|---|
| Phelps[46] | 80 - 90 | 2 - 6 |
| Metcalf and Eddy[11] | 60 - 85 | 2 - 5 |
| Stanley[6] | 70 - 90 | 3 - 5 |
| Imhoff and Fair[13] | 80 - 95* | 1 - 4 |
| Carter | 90 | 2 |
| Carter | 85 | 4 |
| Carter | 75 | 6 |

*Trickling filtration preceeded and followed by plain sedimentation.

TABLE VI

INDIVIDUAL RESULTS OF BIOCHEMICAL OXYGEN DEMAND (B.O.D.) TESTS

Run No: 5
Date: 8/17/50
Time of Sewage
Collection: 8:45-9:15 A.M.

Sewage Settled for 1 Hour
Raw Sewage Temperature: 22.4°C
Dosage Rate: 5.50 mgad

| Sample No. | Titration Results | | Average $Na_2S_2O_3$ Used (ml) | Average Dissolved Oxygen (ppm) | B.O.D. (ppm) |
|---|---|---|---|---|---|
| | Burette Readings (ml) | $Na_2S_2O_3$ Used (ml) | | | |
| $17DW_a$ | 22.00-14.40 | 7.60 | 7.62 | 7.71 | |
| $17DW_a$ | 29.63-22.00 | 7.63 | | | |
| $22DW_a$ | 13.78-6.14 | 7.64 | 7.63 | 7.72 | |
| $22DW_a$ | 21.40-13.78 | 7.62 | | | |
| $17I_{3.33}$ | 21.66-14.26 | 7.40 | 7.34 | 7.43 | 90.1 |
| $17I_{3.33}$ | 28.95-21.66 | 7.29 | | | |
| $22I_{3.33}$ | 19.26-14.94 | 4.32 | 4.38 | 4.43 | |
| $22I_{3.33}$ | 23.70-19.26 | 4.44 | | | |
| $17I_{6.67}$ | 36.15-28.94 | 7.21 | 7.23 | 7.32 | 89.5 |
| $17I_{6.67}$ | 43.40-36.15 | 7.25 | | | |
| $22I_{6.67}$ | 25.00-23.70 | 1.30 | 1.33 | 1.35 | |
| $22I_{6.67}$ | 26.36-25.00 | 1.36 | | | |
| $17E^1_{6.67}$ | 7.30-0.00 | 7.30 | 7.34 | 7.43 | 13.5 |
| $17E^1_{6.67}$ | 14.67-7.30 | 7.37 | | | |
| $22E^1_{6.67}$ | 27.88-21.40 | 6.48 | 6.45 | 6.53 | |
| $22E^1_{6.67}$ | 34.30-27.88 | 6.42 | | | |
| $17E^1_{10}$ | 21.94-14.65 | 7.29 | 7.31 | 7.40 | 11.6 |
| $17E^1_{10}$ | 29.27-21.94 | 7.33 | | | |
| $22E^1_{10}$ | 40.52-34.28 | 6.24 | 6.17 | 6.24 | |
| $22E^1_{10}$ | 46.62-40.52 | 6.10 | | | |

TABLE VII

INDIVIDUAL RESULTS OF BIOCHEMICAL OXYGEN DEMAND (B.O.D.) TESTS

Run No: 6
Date: 8/17/50
Time of Sewage
Collection: 8:45-9:15 A.M.

Sewage Settled for 1 Hour
Raw Sewage Temperature: 22.4°C
Dosage Rate: 6.45 mgad

| Sample No. | Titration Results: Burette Readings (ml) | Titration Results: $Na_2S_2O_3$ Used (ml) | Average $Na_2S_2O_3$ Used (ml) | Average Dissolved Oxygen (ppm) | B.O.D. (ppm) |
|---|---|---|---|---|---|
| $17DW_a$ | 22.00-14.40 | 7.60 | 7.62 | 7.71 | |
| $17DW_a$ | 29.63-22.00 | 7.63 | | | |
| $22DW_a$ | 13.78-6.14 | 7.64 | 7.63 | 7.72 | |
| $22DW_a$ | 21.40-13.78 | 7.62 | | | |
| $17I_{3.33}$ | 21.66-14.26 | 7.40 | 7.34 | 7.43 | 90.1 |
| $17I_{3.33}$ | 28.95-21.66 | 7.29 | | | |
| $22I_{3.33}$ | 19.26-14.94 | 4.32 | 4.38 | 4.43 | |
| $22I_{3.33}$ | 23.70-19.26 | 4.44 | | | |
| $17I_{6.67}$ | 36.15-28.94 | 7.21 | 7.23 | 7.32 | 89.5 |
| $17I_{6.67}$ | 43.40-36.15 | 7.25 | | | |
| $22I_{6.67}$ | 25.00-23.70 | 1.30 | 1.33 | 1.35 | |
| $22I_{6.67}$ | 26.36-25.00 | 1.36 | | | |
| $17E^{3-3}_{6.67}$ | 36.35-29.23 | 7.12 | 7.15 | 7.24 | 15.3 |
| $17E^{3-3}_{6.67}$ | 43.52-36.35 | 7.17 | | | |
| $22E^{3-3}_{6.67}$ | 26.25-20.10 | 6.15 | 6.15 | 6.22 | |
| $22E^{3-3}_{6.67}$ | 32.40-26.25 | 6.15 | | | |
| $17E^{3-3}_{10}$ | 27.25-20.10 | 7.15 | 7.08 | 7.17 | 13.2 |
| $17E^{3-3}_{10}$ | 34.24-27.23 | 7.01 | | | |
| $22E^{3-3}_{10}$ | 38.26-32.40 | 5.86 | 5.78 | 5.85 | |
| $22E^{3-3}_{10}$ | 43.97-38.26 | 5.71 | | | |

TABLE VIII

INDIVIDUAL RESULTS OF BIOCHEMICAL OXYGEN DEMAND (B.O.D.) TESTS

Run No: 7
Date: 8/17/50
Time of Sewage
Collection: 8:45-9:15 A.M.

Sewage Settled for 1 Hour
Raw Sewage Temperature: 22.4°C
Dosage Rate: 1.92 mgad

| Sample No. | Titration Results: Burette Readings (ml) | Titration Results: $Na_2S_2O_3$ Used (ml) | Average $Na_2S_2O_3$ Used (ml) | Average Dissolved Oxygen (ppm) | B.O.D. (ppm) |
|---|---|---|---|---|---|
| 17DW | 7.57-0.00 | 7.57 | 7.61 | 7.70 | |
| 17DW | 15.22-7.57 | 7.65 | | | |
| 22DW | 7.40-0.00 | 7.40 | 7.48 | 7.57 | |
| 22DW | 14.95-7.40 | 7.55 | | | |
| $17I_{3.33}$ | 21.66-14.26 | 7.40 | 7.34 | 7.43 | 90.1 |
| $17I_{3.33}$ | 28.95-21.66 | 7.29 | | | |
| $22I_{3.33}$ | 19.26-14.94 | 4.32 | 4.38 | 4.43 | |
| $22I_{3.33}$ | 23.70-19.26 | 4.44 | | | |
| $17I_{6.67}$ | 36.15-28.94 | 7.21 | 7.23 | 7.32 | 89.5 |
| $17I_{6.67}$ | 43.40-36.15 | 7.25 | | | |
| $22I_{6.67}$ | 25.00-23.70 | 1.30 | 1.33 | 1.35 | |
| $22I_{6.67}$ | 26.36-25.00 | 1.36 | | | |
| $17E^{4-3}_{6.67}$ | 7.20-0.02 | 7.18 | 7.20 | 7.29 | 14.1 |
| $17E^{4-3}_{6.67}$ | 14.42-7.20 | 7.22 | | | |
| $22E^{4-3}_{6.67}$ | 32.60-26.36 | 6.24 | 6.27 | 6.35 | |
| $22E^{4-3}_{6.67}$ | 38.90-32.60 | 6.30 | | | |
| $17E^{4-3}_{10}$ | 36.97-29.61 | 7.36 | 7.39 | 7.48 | 12.8 |
| $17E^{4-3}_{10}$ | 44.38-36.97 | 7.41 | | | |
| $22E^{4-3}_{10}$ | 45.01-38.90 | 6.11 | 6.13 | 6.20 | |
| $22E^{4-3}_{10}$ | 6.15-0.00 | 6.15 | | | |

TABLE IX

INDIVIDUAL RESULTS ON SPIKED SEWAGE RUNS

Run No: 15
Date: 12/7-8/50

Raw Sewage Temperature: 19.4°C
Dosage Rates
Filter No. 2: 2.09 mgad
Filter No. 4: 1.91 mgad

| Sample No. | Average c/m/ml | Time of Collection* (min) | Time of Collection* (hr) | Time of Counting* (min) | Time of Counting* (hr) | Depth Sample Taken from (ft) | Average c/m/ml Corrected for Decay | Initial Activity Remaining (%) | Decay Correction Factor |
|---|---|---|---|---|---|---|---|---|---|
| $15I_o$ | 966 | -3 | -0.050 | 370 | 6.167 | Tank | 985 | | 1.02 |
| 15a-0-2 | 986 | 138 | 2.300 | 365 | 6.083 | 0 | 1006 | 99.3 | 1.02 |
| 15b-0-2 | 987 | 277 | 4.617 | 498 | 8.300 | 0 | 1017 | 100.4 | 1.03 |
| 15c-0-2 | 974 | 443 | 7.383 | 642 | 10.700 | 0 | 1013 | 100.0 | 1.04 |
| 15d-0-2 | 979 | 690 | 11.500 | 789 | 13.150 | 0 | 1028 | 101.5 | 1.05 |
| 15e-0-2 | 947 | 928 | 15.467 | 1012 | 16.867 | 0 | 1013 | 100.0 | 1.07 |
| 15f-0-2 | 938 | 1123 | 18.717 | 1203 | 20.050 | 0 | 1004 | 99.1 | 1.07 |
| 15a-0-4 | 1001 | 144 | 2.400 | 377 | 6.283 | 0 | 1021 | 102.4 | 1.02 |
| 15b-0-4 | 961 | 282 | 4.700 | 503 | 8.383 | 0 | 990 | 99.3 | 1.03 |
| 15c-0-4 | 949 | 447 | 7.450 | 647 | 10.783 | 0 | 987 | 99.0 | 1.04 |
| 15d-0-4 | 949 | 695 | 11.583 | 804 | 13.400 | 0 | 997 | 100.0 | 1.05 |
| 15e-0-4 | 949 | 933 | 15.550 | 1017 | 16.950 | 0 | 1015 | 101.8 | 1.07 |
| 15f-0-4 | 908 | 1127 | 18.783 | 1207 | 20.117 | 0 | 972 | 97.5 | 1.07 |
| 15a-1-2 | 488 | 122 | 2.033 | 383 | 6.383 | 1 | 498 | 49.2 | 1.02 |
| 15b-1-2 | 371 | 269 | 4.483 | 510 | 8.500 | 1 | 382 | 37.7 | 1.03 |
| 15c-1-2 | 536 | 435 | 7.250 | 653 | 10.883 | 1 | 557 | 55.0 | 1.04 |
| 15d-1-2 | 451 | 679 | 11.317 | 810 | 13.500 | 1 | 474 | 46.8 | 1.05 |
| 15e-1-2 | 568 | 921 | 15.350 | 1023 | 17.050 | 1 | 608 | 60.0 | 1.07 |
| 15f-1-2 | 591 | 1116 | 18.600 | 1221 | 20.350 | 1 | 632 | 62.4 | 1.07 |
| 15a-1-4 | 229 | 127 | 2.117 | 394 | 6.567 | 1 | 234 | 23.5 | 1.02 |
| 15b-1-4 | 417 | 263 | 4.383 | 519 | 8.650 | 1 | 430 | 43.0 | 1.03 |
| 15c-1-4 | 417 | 435 | 7.250 | 672 | 11.200 | 1 | 434 | 43.5 | 1.04 |

(continued on next page)

TABLE IX
(continued)

| Sample No. | Average c/m/ml | Time of Collection* (min) | Time of Collection* (hr) | Time of Counting* (min) | Time of Counting* (hr) | Depth Sample Taken from (ft) | Average c/m/ml Corrected for Decay | Initial Activity Remaining (%) | Decay Correction Factor |
|---|---|---|---|---|---|---|---|---|---|
| 15d-1-4 | 443 | 670 | 11.167 | 816 | 13.600 | 1 | 465 | 46.6 | 1.05 |
| 15e-1-4 | 581 | 919 | 15.317 | 1029 | 17.150 | 1 | 622 | 62.4 | 1.07 |
| 15f-1-4 | 671 | 1114 | 18.567 | 1213 | 20.217 | 1 | 718 | 72.0 | 1.07 |
| 15a-2-2 | 224 | 108 | 1.800 | 405 | 6.750 | 2 | 231 | 22.8 | 1.03 |
| 15b-2-2 | 242 | 246 | 4.100 | 528 | 8.800 | 2 | 252 | 24.9 | 1.04 |
| 15c-2-2 | 257 | 422 | 7.033 | 681 | 11.350 | 2 | 267 | 26.4 | 1.04 |
| 15d-2-2 | 226 | 658 | 10.967 | 826 | 13.767 | 2 | 237 | 23.4 | 1.05 |
| 15e-2-2 | 324 | 901 | 15.017 | 1037 | 17.283 | 2 | 347 | 34.3 | 1.07 |
| 15f-2-2 | 346 | 1107 | 18.450 | 1229 | 20.483 | 2 | 374 | 36.9 | 1.08 |
| 15a-2-4 | 199 | 102 | 1.700 | 415 | 6.917 | 2 | 205 | 20.6 | 1.03 |
| 15b-2-4 | 215 | 239 | 3.983 | 551 | 9.183 | 2 | 224 | 22.5 | 1.04 |
| 15c-2-4 | 221 | 421 | 7.017 | 727 | 12.117 | 2 | 232 | 23.3 | 1.05 |
| 15d-2-4 | 222 | 645 | 10.750 | 837 | 13.950 | 2 | 233 | 23.4 | 1.05 |
| 15e-2-4 | 397 | 899 | 14.983 | 1046 | 17.433 | 2 | 425 | 42.6 | 1.07 |
| 15f-2-4 | 375 | 1093 | 18.217 | 1240 | 20.667 | 2 | 405 | 40.6 | 1.08 |
| 15a-3-2 | 71 | 88 | 1.467 | 427 | 7.117 | 3 | 73 | 7.2 | 1.03 |
| 15b-3-2 | 139 | 223 | 3.717 | 562 | 9.367 | 3 | 143 | 14.1 | 1.03 |
| 15c-3-2 | 113 | 406 | 6.767 | 738 | 12.300 | 3 | 119 | 11.7 | 1.05 |
| 15d-3-2 | 200 | 633 | 10.550 | 848 | 14.133 | 3 | 210 | 20.7 | 1.05 |
| 15e-3-2 | 169 | 889 | 14.817 | 1054 | 17.567 | 3 | 181 | 17.9 | 1.07 |
| 15f-3-2 | 182 | 1078 | 17.967 | 1251 | 20.850 | 3 | 197 | 19.5 | 1.08 |
| 15a-3-4 | 81 | 86 | 1.433 | 456 | 7.600 | 3 | 83 | 8.3 | 1.03 |
| 15b-3-4 | 120 | 224 | 3.733 | 601 | 10.017 | 3 | 125 | 12.5 | 1.04 |
| 15c-3-4 | 149 | 408 | 6.800 | 749 | 12.483 | 3 | 157 | 15.8 | 1.05 |
| 15d-3-4 | 148 | 631 | 10.517 | 859 | 14.317 | 3 | 155 | 15.6 | 1.05 |
| 15e-3-4 | 305 | 889 | 14.817 | 1062 | 17.700 | 3 | 326 | 32.7 | 1.07 |
| 15f-3-4 | 307 | 1080 | 18.000 | 1269 | 21.150 | 3 | 332 | 33.3 | 1.08 |

(continued on next page)

TABLE IX
(continued)

| Sample No. | Average c/m/ml | Time of Collection* (min) | Time of Collection* (hr) | Time of Counting* (min) | Time of Counting* (hr) | Depth Sample Taken from (ft) | Average c/m/ml Corrected for Decay | Initial Activity Remaining (%) | Decay Correction Factor |
|---|---|---|---|---|---|---|---|---|---|
| 15a-5-2 | 39 | 62 | 1.033 | 468 | 7.800 | 5 | 40 | 4.0 | 1.03 |
| 15b-5-2 | 91 | 207 | 3.450 | 612 | 10.200 | 5 | 95 | 9.4 | 1.04 |
| 15c-5-2 | 74 | 390 | 6.500 | 759 | 12.650 | 5 | 78 | 7.7 | 1.05 |
| 15d-5-2 | 114 | 615 | 10.250 | 870 | 14.500 | 5 | 121 | 12.0 | 1.06 |
| 15e-5-2 | 156 | 871 | 14.517 | 1178 | 19.633 | 5 | 169 | 16.7 | 1.08 |
| 15f-5-2 | 124 | 1068 | 17.800 | 1278 | 21.300 | 5 | 134 | 13.2 | 1.08 |
| 15a-6-2 | 29 | 36 | 0.600 | 479 | 7.983 | 6 | 30 | 3.0 | 1.03 |
| 15b-6-2 | 69 | 189 | 3.150 | 622 | 10.367 | 6 | 72 | 7.1 | 1.04 |
| 15c-6-2 | 68 | 368 | 6.133 | 770 | 12.833 | 6 | 71 | 7.0 | 1.05 |
| 15d-6-2 | 95 | 599 | 9.983 | 881 | 14.683 | 6 | 101 | 10.0 | 1.06 |
| 15e-6-2 | 165 | 855 | 14.250 | 1186 | 19.767 | 6 | 178 | 17.6 | 1.08 |
| 15f-6-2 | 115 | 1050 | 17.500 | 1289 | 21.483 | 6 | 124 | 12.2 | 1.08 |
| 15a-6-4 | 45 | 35 | 0.583 | 490 | 8.167 | 6 | 46 | 4.6 | 1.03 |
| 15b-6-4 | 61 | 189 | 3.150 | 633 | 10.550 | 6 | 63 | 6.3 | 1.04 |
| 15c-6-4 | 86 | 366 | 6.100 | 781 | 13.017 | 6 | 90 | 9.0 | 1.05 |
| 15d-6-4 | 110 | 600 | 10.000 | 1004 | 16.733 | 6 | 118 | 11.8 | 1.07 |
| 15e-6-4 | 187 | 854 | 14.233 | 1195 | 19.917 | 6 | 202 | 20.3 | 1.08 |
| 15f-6-4 | 135 | 1044 | 17.400 | 1300 | 21.677 | 6 | 146 | 14.6 | 1.08 |

*Calculated from start of run at 12:50 P.M., 12/7/50.

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TABLE X

INDIVIDUAL RESULTS ON SPIKED SEWAGE RUNS

Run No: 15
Date: 12/7-8/50
Background: 25-29 C/M

Raw Sewage Temperature: 19.4°C
Dosage Rates
Filter No. 2: 2.09 mgad
Filter No. 4: 1.91 mgad

| Sample No. | Recorder Reading (value x 64) | Lights (counts) | Counting Time (min) | Counts per Minute (C/M) | C/M Corrected for Background (CCB) | Counts per Minute per Milliliter (c/m/ml) | Sample Volume (ml) |
|---|---|---|---|---|---|---|---|
| $15I_o$ | 152 | 4 | 2 | 4866 | 4839 | 968 | 5 |
| $15I_o$ | 152 | 10 | 2 | 4869 | 4842 | 968 | 5 |
| $15I_o$ | 151 | 22 | 2 | 4843 | 4816 | 963 | 5 |
| 15a-0-2 | 154 | 33 | 2 | 4945 | 4918 | 984 | 5 |
| 15a-0-2 | 155 | 1 | 2 | 4961 | 4934 | 987 | 5 |
| 15a-0-4 | 160 | 3 | 2 | 5122 | 5095 | 1019 | 5 |
| 15a-0-4 | 154 | 15 | 2 | 4936 | 4909 | 982 | 5 |
| 15a-1-2 | 116 | 39 | 3 | 2488 | 2461 | 492 | 5 |
| 15a-1-2 | 114 | 51 | 3 | 2449 | 2422 | 484 | 5 |
| 15a-1-4 | 92 | 24 | 5 | 1182 | 1155 | 231 | 5 |
| 15a-1-4 | 90 | 45 | 5 | 1161 | 1134 | 227 | 5 |
| 15a-2-2 | 90 | 24 | 5 | 1157 | 1130 | 226 | 5 |
| 15a-2-2 | 88 | 50 | 5 | 1136 | 1109 | 222 | 5 |
| 15a-2-4 | 79 | 33 | 5 | 1018 | 991 | 198 | 5 |
| 15a-2-4 | 79 | 61 | 5 | 1023 | 996 | 199 | 5 |
| 15a-3-2 | 56 | 46 | 5 | 726 | 699 | 70 | 10 |
| 15a-3-2 | 58 | 38 | 5 | 750 | 723 | 72 | 10 |
| 15a-3-4 | 65 | 3 | 5 | 833 | 807 | 81 | 10 |
| 15a-3-4 | 64 | 41 | 5 | 827 | 801 | 80 | 10 |
| 15a-5-2 | 32 | 17 | 5 | 413 | 387 | 39 | 10 |
| 15a-5-2 | 38 | 45 | 6 | 413 | 387 | 39 | 10 |
| 15a-6-2 | 23 | 24 | 5 | 299 | 273 | 27 | 10 |
| 15a-6-2 | 25 | 44 | 5 | 329 | 303 | 30 | 10 |

(continued on next page)

TABLE X
(continued)

| Sample No. | Recorder Reading (value x 64) | Lights (counts) | Counting Time (min) | Counts per Minute (C/M) | C/M Corrected for Background (CCB) | Counts per Minute per Milliliter (c/m/ml) | Sample Volume (ml) |
|---|---|---|---|---|---|---|---|
| 15a-6-4 | 37 | 4 | 5 | 474 | 448 | 45 | 10 |
| 15a-6-4 | 37 | 5 | 5 | 475 | 449 | 45 | 10 |
| 15b-0-2 | 156 | 49 | 2 | 5017 | 4991 | 998 | 5 |
| 15b-0-2 | 153 | 5 | 2 | 4899 | 4873 | 975 | 5 |
| 15b-0-4 | 149 | 33 | 2 | 4785 | 4759 | 952 | 5 |
| 15b-0-4 | 152 | 11 | 2 | 4870 | 4844 | 969 | 5 |
| 15b-1-2 | 120 | 48 | 4 | 1932 | 1906 | 381 | 5 |
| 15b-1-2 | 114 | 2 | 4 | 1825 | 1799 | 360 | 5 |
| 15b-1-4 | 127 | 24 | 4 | 2038 | 2012 | 402 | 5 |
| 15b-1-4 | 136 | 16 | 4 | 2180 | 2154 | 431 | 5 |
| 15b-2-2 | 97 | 1 | 5 | 1242 | 1216 | 243 | 5 |
| 15b-2-2 | 95 | 57 | 5 | 1227 | 1201 | 240 | 5 |
| 15b-2-4 | 85 | 14 | 5 | 1091 | 1066 | 213 | 5 |
| 15b-2-4 | 86 | 11 | 5 | 1103 | 1078 | 216 | 5 |
| 15b-3-2 | 109 | 63 | 5 | 1408 | 1383 | 138 | 10 |
| 15b-3-2 | 111 | 20 | 5 | 1425 | 1400 | 140 | 10 |
| 15b-3-4 | 97 | 23 | 5 | 1246 | 1221 | 122 | 10 |
| 15b-3-4 | 94 | 15 | 5 | 1206 | 1181 | 118 | 10 |
| 15b-5-2 | 70 | 49 | 5 | 906 | 881 | 88 | 10 |
| 15b-5-2 | 75 | 29 | 5 | 966 | 941 | 94 | 10 |
| 15b-6-2 | 54 | 32 | 5 | 698 | 673 | 67 | 10 |
| 15b-6-2 | 56 | 56 | 5 | 728 | 703 | 70 | 10 |
| 15b-6-4 | 49 | 14 | 5 | 630 | 605 | 61 | 10 |
| 15b-6-4 | 48 | 42 | 5 | 623 | 598 | 60 | 10 |
| 15c-0-2 | 153 | 3 | 2 | 4898 | 4873 | 975 | 5 |
| 15c-0-2 | 152 | 50 | 2 | 4889 | 4864 | 973 | 5 |
| 15c-0-4 | 151 | 8 | 2 | 4836 | 4811 | 962 | 5 |
| 15c-0-4 | 147 | 5 | 2 | 4707 | 4682 | 936 | 5 |

(continued on next page)

TABLE X
(continued)

| Sample No. | Recorder Reading (value x 64) | Lights (counts) | Counting Time (min) | Counts per Minute (C/M) | C/M Corrected for Background (CCB) | Counts per Minute per Milliliter (c/m/ml) | Sample Volume (ml) |
|---|---|---|---|---|---|---|---|
| 15c-1-2 | 126 | 50 | 3 | 2705 | 2680 | 536 | 5 |
| 15c-1-2 | 126 | 49 | 3 | 2704 | 2679 | 536 | 5 |
| 15c-1-4 | 131 | 28 | 4 | 2103 | 2077 | 415 | 5 |
| 15c-1-4 | 99 | 5 | 3 | 2114 | 2088 | 418 | 5 |
| 15c-2-2 | 102 | 11 | 5 | 1308 | 1282 | 256 | 5 |
| 15c-2-2 | 102 | 49 | 5 | 1315 | 1289 | 258 | 5 |
| 15c-2-4 | 116 | 0 | 6 | 1067 | 1041 | 208 | 5 |
| 15c-2-4 | 93 | 6 | 5 | 1192 | 1166 | 233 | 5 |
| 15c-3-2 | 90 | 60 | 5 | 1164 | 1138 | 114 | 10 |
| 15c-3-2 | 89 | 14 | 5 | 1142 | 1116 | 112 | 10 |
| 15c-3-4 | 120 | 1 | 5 | 1536 | 1510 | 151 | 10 |
| 15c-3-4 | 116 | 27 | 5 | 1490 | 1464 | 146 | 10 |
| 15c-5-2 | 60 | 38 | 5 | 776 | 750 | 75 | 10 |
| 15c-5-2 | 58 | 41 | 5 | 751 | 725 | 73 | 10 |
| 15c-6-2 | 46 | 18 | 5 | 592 | 566 | 57 | 10 |
| 15c-6-2 | 47 | 12 | 5 | 604 | 578 | 78 | 10 |
| 15c-6-4 | 69 | 7 | 5 | 885 | 859 | 86 | 10 |
| 15c-6-4 | 68 | 29 | 5 | 876 | 850 | 85 | 10 |
| 15d-0-2 | 153 | 60 | 2 | 4926 | 4900 | 980 | 5 |
| 15d-0-2 | 153 | 44 | 2 | 4918 | 4892 | 978 | 5 |
| 15d-0-4 | 149 | 24 | 2 | 4780 | 4753 | 951 | 5 |
| 15d-0-4 | 148 | 56 | 2 | 4764 | 4737 | 947 | 5 |
| 15d-1-2 | 104 | 61 | 3 | 2239 | 2212 | 442 | 5 |
| 15d-1-2 | 109 | 6 | 3 | 2327 | 2300 | 460 | 5 |
| 15d-1-4 | 103 | 51 | 3 | 2214 | 2187 | 437 | 5 |
| 15d-1-4 | 106 | 14 | 3 | 2266 | 2239 | 448 | 5 |
| 15d-2-2 | 89 | 61 | 5 | 1151 | 1124 | 225 | 5 |
| 15d-2-2 | 90 | 39 | 5 | 1160 | 1133 | 227 | 5 |

(continued on next page)

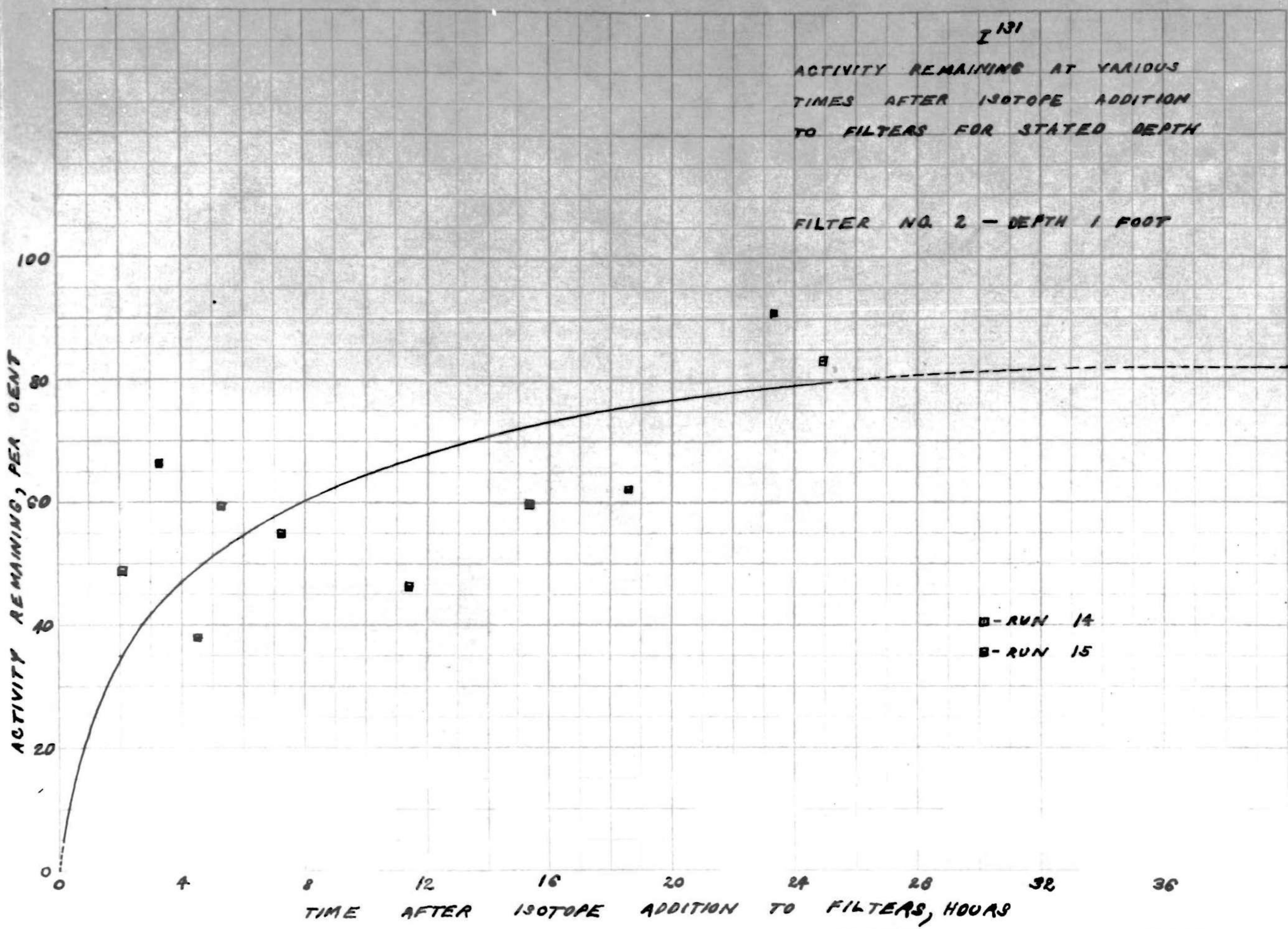
TABLE X
(continued)

| Sample No. | Recorder Reading (value x 64) | Lights (counts) | Counting Time (min) | Counts per Minute (C/M) | C/M Corrected for Background (CCB) | Counts per Minute per Milliliter (c/m/ml) | Sample Volume (ml) |
|---|---|---|---|---|---|---|---|
| 15d-2-4 | 86 | 54 | 5 | 1112 | 1085 | 217 | 5 |
| 15d-2-4 | 90 | 40 | 5 | 1160 | 1133 | 227 | 5 |
| 15d-3-2 | 125 | 12 | 4 | 2003 | 1976 | 198 | 10 |
| 15d-3-2 | 191 | 28 | 6 | 2042 | 2015 | 202 | 10 |
| 15d-3-4 | 120 | 27 | 5 | 1541 | 1514 | 151 | 10 |
| 15d-3-4 | 114 | 37 | 5 | 1467 | 1440 | 144 | 10 |
| 15d-5-2 | 91 | 21 | 5 | 1169 | 1142 | 114 | 10 |
| 15d-5-2 | 90 | 12 | 5 | 1154 | 1127 | 113 | 10 |
| 15d-6-2 | 76 | 15 | 5 | 976 | 949 | 95 | 10 |
| 15d-6-2 | 75 | 13 | 5 | 963 | 936 | 94 | 10 |
| 15d-6-4 | 89 | 12 | 5 | 1142 | 1115 | 112 | 10 |
| 15d-6-4 | 86 | 9 | 5 | 1103 | 1076 | 108 | 10 |
| 15e-0-2 | 148 | 8 | 2 | 4740 | 4713 | 943 | 5 |
| 15e-0-2 | 149 | 17 | 2 | 4777 | 4750 | 950 | 5 |
| 15e-0-4 | 148 | 19 | 2 | 4746 | 4719 | 944 | 5 |
| 15e-0-4 | 149 | 60 | 2 | 4798 | 4771 | 954 | 5 |
| 15e-1-2 | 131 | 10 | 3 | 2798 | 2771 | 554 | 5 |
| 15e-1-2 | 137 | 39 | 3 | 2936 | 2909 | 582 | 5 |
| 15e-1-4 | 139 | 6 | 3 | 2967 | 2940 | 588 | 5 |
| 15e-1-4 | 135 | 56 | 3 | 2899 | 2872 | 574 | 5 |
| 15e-2-2 | 103 | 40 | 4 | 1658 | 1631 | 326 | 5 |
| 15e-2-2 | 102 | 18 | 4 | 1637 | 1610 | 322 | 5 |
| 15e-2-4 | 141 | 29 | 4 | 1763 | 1736 | 347 | 5 |
| 15e-2-4 | 106 | 5 | 3 | 2263 | 2236 | 447 | 5 |
| 15e-3-2 | 107 | 28 | 4 | 1719 | 1692 | 169 | 10 |
| 15e-3-2 | 107 | 34 | 4 | 1721 | 1694 | 169 | 10 |
| 15e-3-4 | 145 | 60 | 3 | 3113 | 3086 | 309 | 10 |
| 15e-3-4 | 141 | 45 | 3 | 3023 | 2996 | 300 | 10 |

(continued on next page)

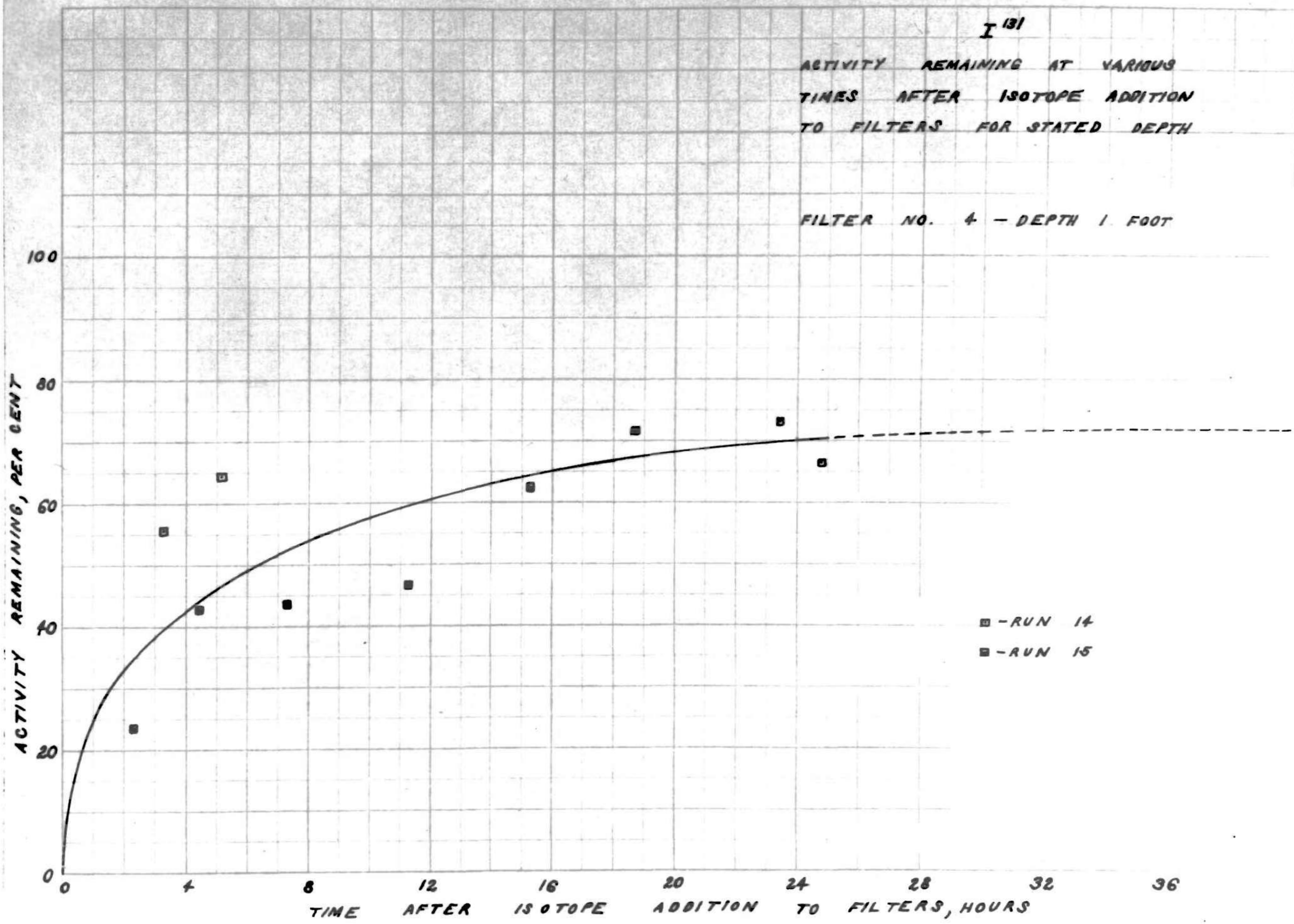
TABLE X
(continued)

| Sample No. | Recorder Reading (value x 64) | Lights (counts) | Counting Time (min) | Counts per Minute (C/M) | C/M Corrected for Background (CCB) | Counts per Minute per Milliliter (c/m/ml) | Sample Volume (ml) |
|---|---|---|---|---|---|---|---|
| 15e-5-2 | 122 | 23 | 5 | 1566 | 1537 | 154 | 10 |
| 15e-5-2 | 100 | 9 | 4 | 1602 | 1573 | 157 | 10 |
| 15e-6-2 | 104 | 14 | 4 | 1668 | 1639 | 164 | 10 |
| 15e-6-2 | 105 | 6 | 4 | 1682 | 1653 | 165 | 10 |
| 15e-6-4 | 117 | 36 | 4 | 1881 | 1852 | 185 | 10 |
| 15e-6-4 | 120 | 12 | 4 | 1923 | 1894 | 189 | 10 |
| 15f-0-2 | 147 | 10 | 2 | 4709 | 4680 | 936 | 5 |
| 15f-0-2 | 147 | 53 | 2 | 4731 | 4702 | 940 | 5 |
| 15f-0-4 | 140 | 62 | 2 | 4511 | 4482 | 896 | 5 |
| 15f-0-4 | 144 | 40 | 2 | 4628 | 4599 | 920 | 5 |
| 15f-1-2 | 185 | 53 | 4 | 2973 | 2944 | 589 | 5 |
| 15f-1-2 | 140 | 15 | 3 | 2992 | 2963 | 593 | 5 |
| 15f-1-4 | 107 | 46 | 2 | 3447 | 3418 | 684 | 5 |
| 15f-1-4 | 103 | 39 | 2 | 3316 | 3287 | 657 | 5 |
| 15f-2-2 | 108 | 24 | 4 | 1734 | 1705 | 341 | 5 |
| 15f-2-2 | 111 | 28 | 4 | 1783 | 1754 | 351 | 5 |
| 15f-2-4 | 117 | 10 | 4 | 1875 | 1846 | 369 | 5 |
| 15f-2-4 | 121 | 0 | 4 | 1936 | 1907 | 381 | 5 |
| 15f-3-2 | 113 | 62 | 4 | 1824 | 1795 | 180 | 10 |
| 15f-3-2 | 116 | 16 | 4 | 1860 | 1831 | 183 | 10 |
| 15f-3-4 | 148 | 12 | 3 | 3161 | 3132 | 313 | 10 |
| 15f-3-4 | 142 | 9 | 3 | 3032 | 3003 | 300 | 10 |
| 15f-5-2 | 103 | 11 | 5 | 1321 | 1292 | 129 | 10 |
| 15f-5-2 | 95 | 0 | 5 | 1216 | 1187 | 119 | 10 |
| 15f-6-2 | 90 | 10 | 5 | 1154 | 1125 | 113 | 10 |
| 15f-6-2 | 92 | 44 | 5 | 1186 | 1157 | 116 | 10 |
| 15f-6-4 | 107 | 14 | 5 | 1372 | 1343 | 134 | 10 |
| 15f-6-4 | 107 | 20 | 5 | 1374 | 1345 | 135 | 10 |



$I^{131}$
ACTIVITY REMAINING AT VARIOUS TIMES AFTER ISOTOPE ADDITION TO FILTERS FOR STATED DEPTH
FILTER NO. 2 – DEPTH 1 FOOT
▫ - RUN 14
▪ - RUN 15
ACTIVITY REMAINING, PER CENT
0
20
40
60
80
100
0
4
8
12
16
20
24
28
32
36
TIME AFTER ISOTOPE ADDITION TO FILTERS, HOURS


FIGURE 9



$I^{131}$
ACTIVITY REMAINING AT VARIOUS TIMES AFTER ISOTOPE ADDITION TO FILTERS FOR STATED DEPTH
FILTER NO. 4 – DEPTH 1 FOOT
– RUN 14
– RUN 15
ACTIVITY REMAINING, PER CENT
0
20
40
60
80
100
0
4
8
12
16
20
24
28
32
36
TIME AFTER ISOTOPE ADDITION TO FILTERS, HOURS


FIGURE 10

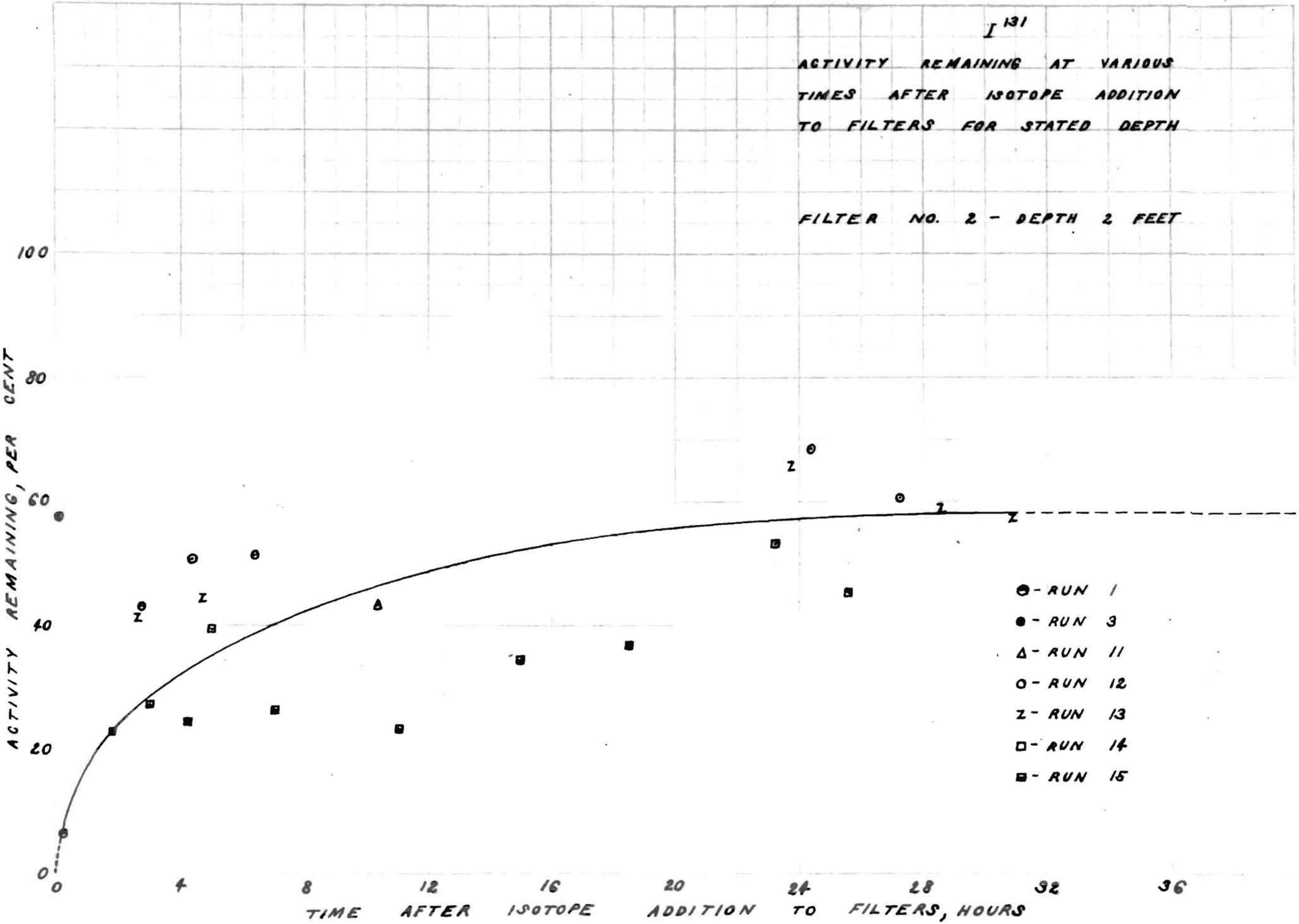
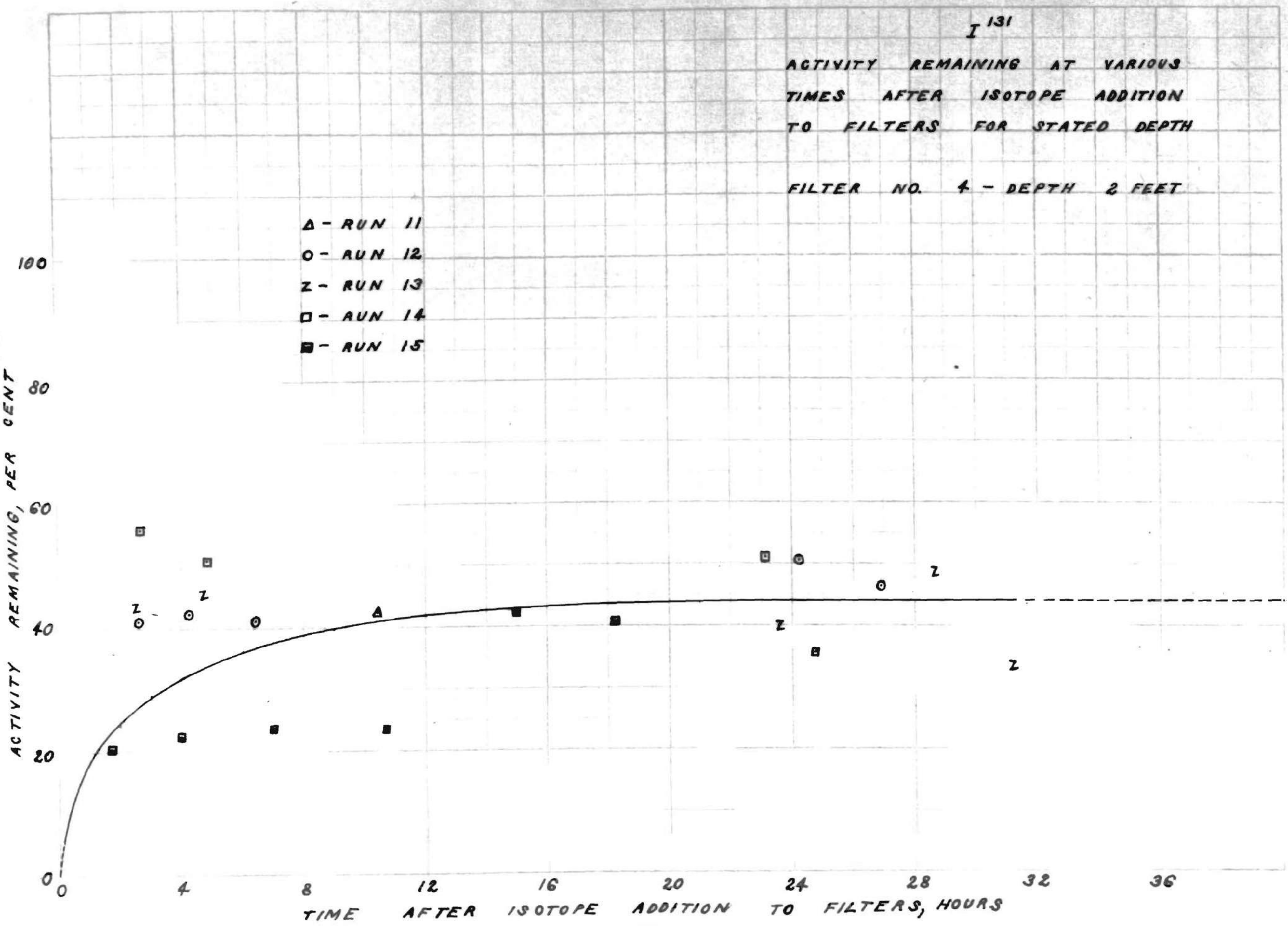
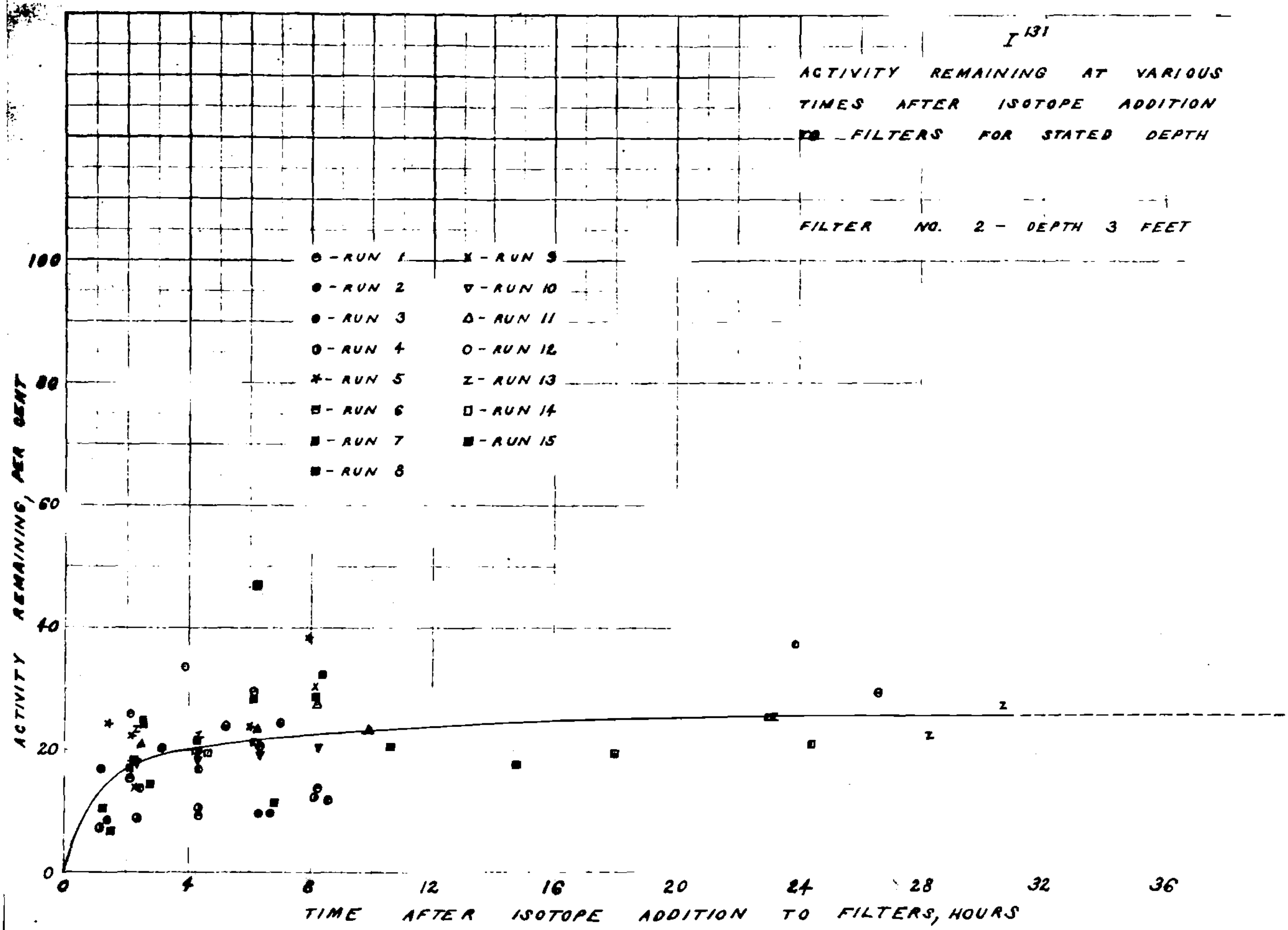

I 131
ACTIVITY REMAINING AT VARIOUS TIMES AFTER ISOTOPE ADDITION TO FILTERS FOR STATED DEPTH
FILTER NO. 2 - DEPTH 2 FEET
ACTIVITY REMAINING, PER CENT
0
20
40
60
80
100
TIME AFTER ISOTOPE ADDITION TO FILTERS, HOURS
0
4
8
12
16
20
24
28
32
36
⊖ - RUN 1
● - RUN 3
Δ - RUN 11
O - RUN 12
Z - RUN 13
□ - RUN 14
■ - RUN 15

FIGURE 11



$I^{131}$
ACTIVITY REMAINING AT VARIOUS TIMES AFTER ISOTOPE ADDITION TO FILTERS FOR STATED DEPTH
FILTER NO. 4 - DEPTH 2 FEET
Δ - RUN 11
O - RUN 12
Z - RUN 13
□ - RUN 14
■ - RUN 15
ACTIVITY REMAINING, PER CENT
0
20
40
60
80
100
0
4
8
12
16
20
24
28
32
36
TIME AFTER ISOTOPE ADDITION TO FILTERS, HOURS


FIGURE 12



$I^{131}$
ACTIVITY REMAINING AT VARIOUS TIMES AFTER ISOTOPE ADDITION TO FILTERS FOR STATED DEPTH
FILTER NO. 2 - DEPTH 3 FEET
⊖ - RUN 1
● - RUN 2
● - RUN 3
◐ - RUN 4
✱ - RUN 5
⊟ - RUN 6
■ - RUN 7
■ - RUN 8
X - RUN 9
▽ - RUN 10
Δ - RUN 11
O - RUN 12
Z - RUN 13
□ - RUN 14
■ - RUN 15
ACTIVITY REMAINING, PER CENT
0
20
40
60
80
100
0
4
8
12
16
20
24
28
32
36
TIME AFTER ISOTOPE ADDITION TO FILTERS, HOURS


FIGURE 13

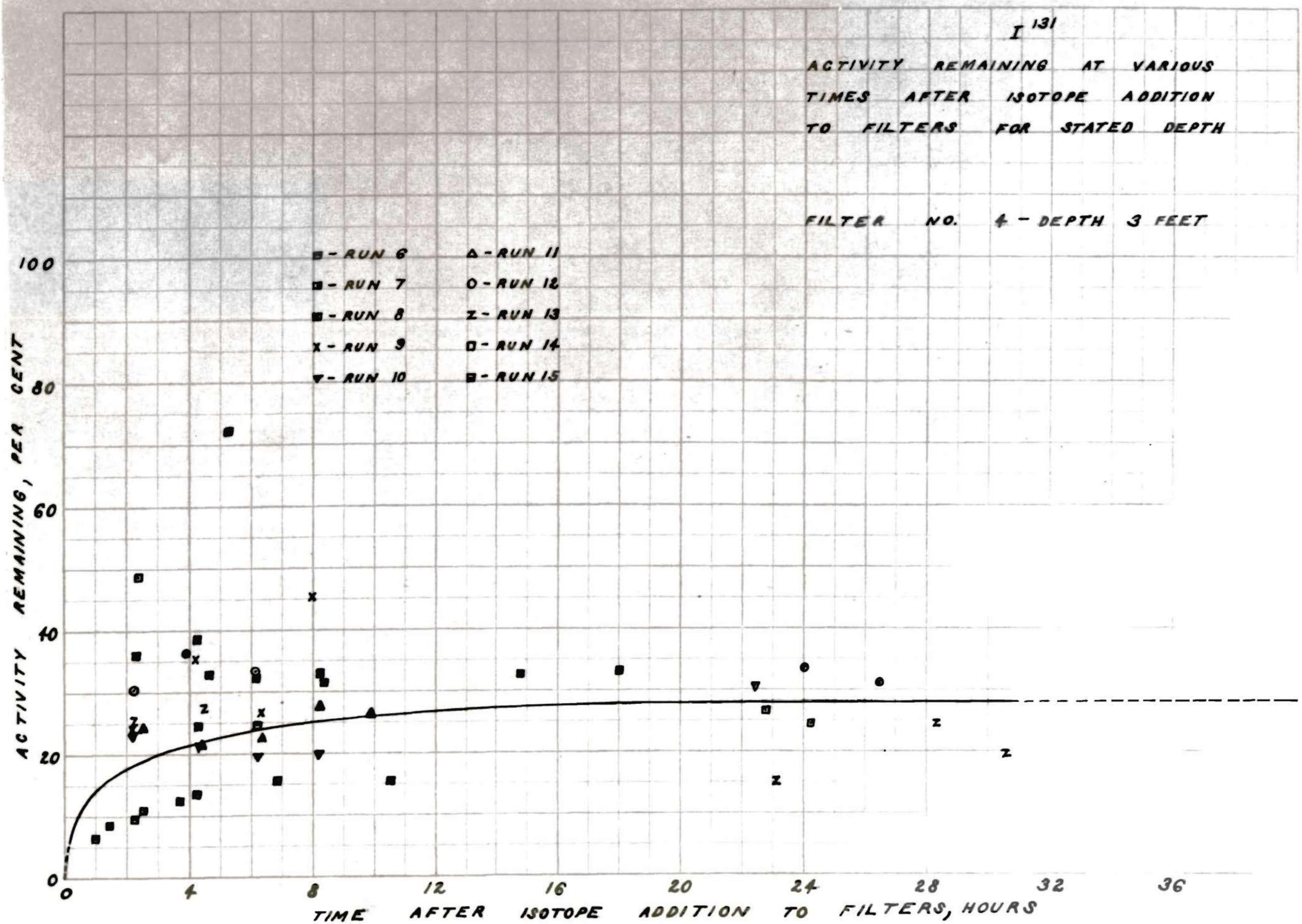

$I^{131}$
ACTIVITY REMAINING AT VARIOUS TIMES AFTER ISOTOPE ADDITION TO FILTERS FOR STATED DEPTH
FILTER NO. 4 - DEPTH 3 FEET
- RUN 6
- RUN 7
- RUN 8
X - RUN 9
▼- RUN 10
Δ - RUN 11
O - RUN 12
Z - RUN 13
□ - RUN 14
- RUN 15
ACTIVITY REMAINING, PER CENT
100
80
60
40
20
0
0
4
8
12
16
20
24
28
32
36
TIME AFTER ISOTOPE ADDITION TO FILTERS, HOURS

FIGURE 14

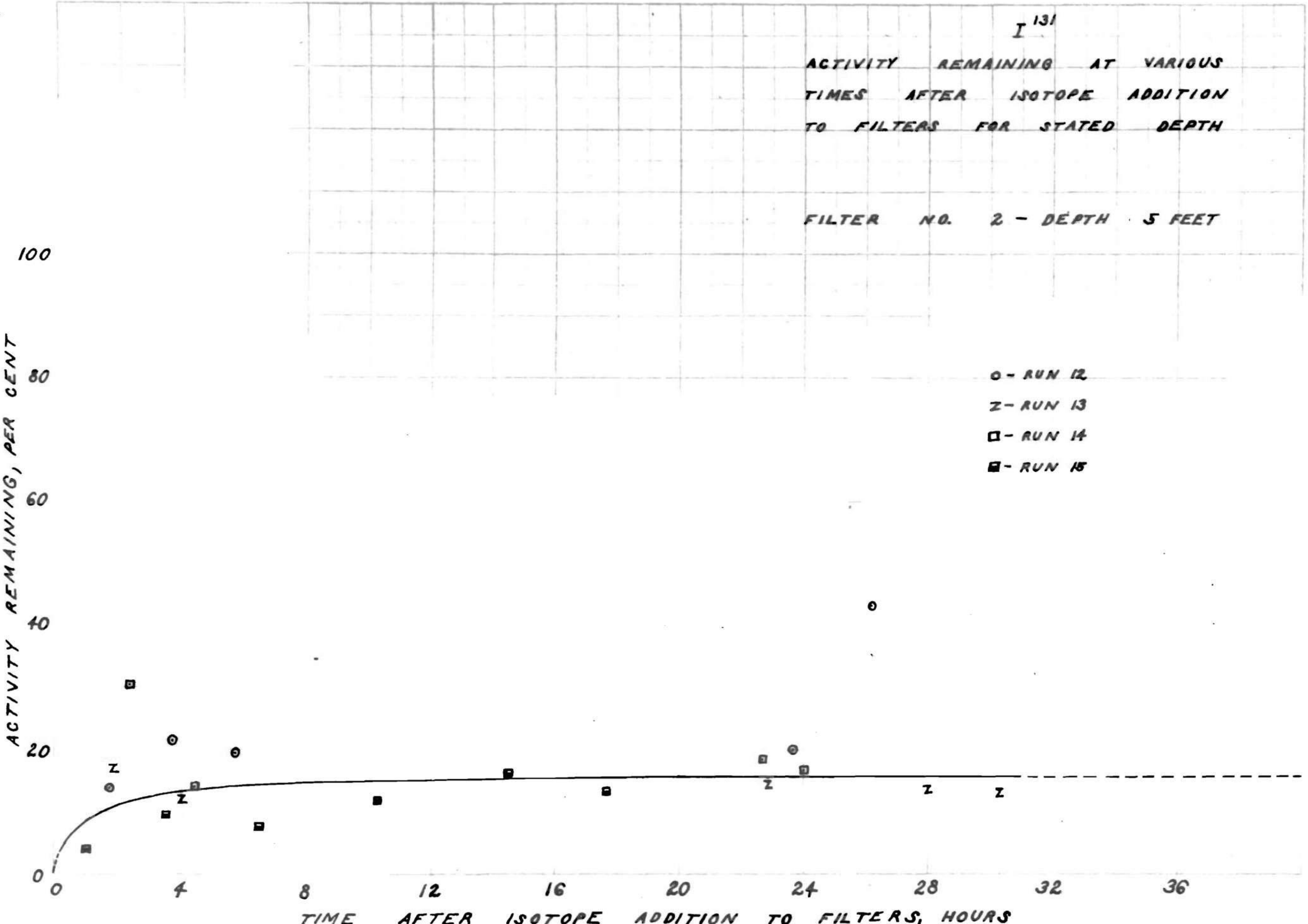
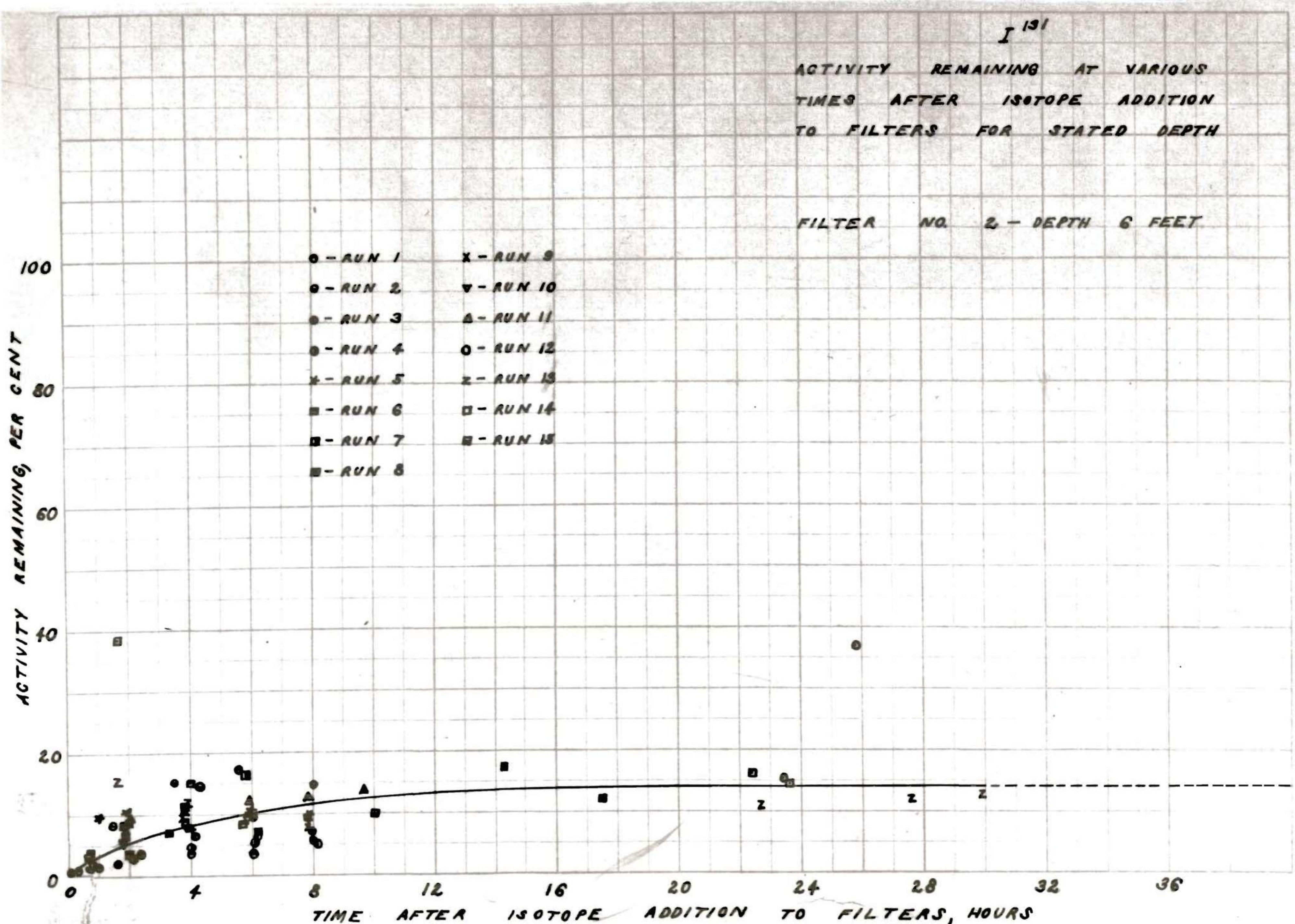
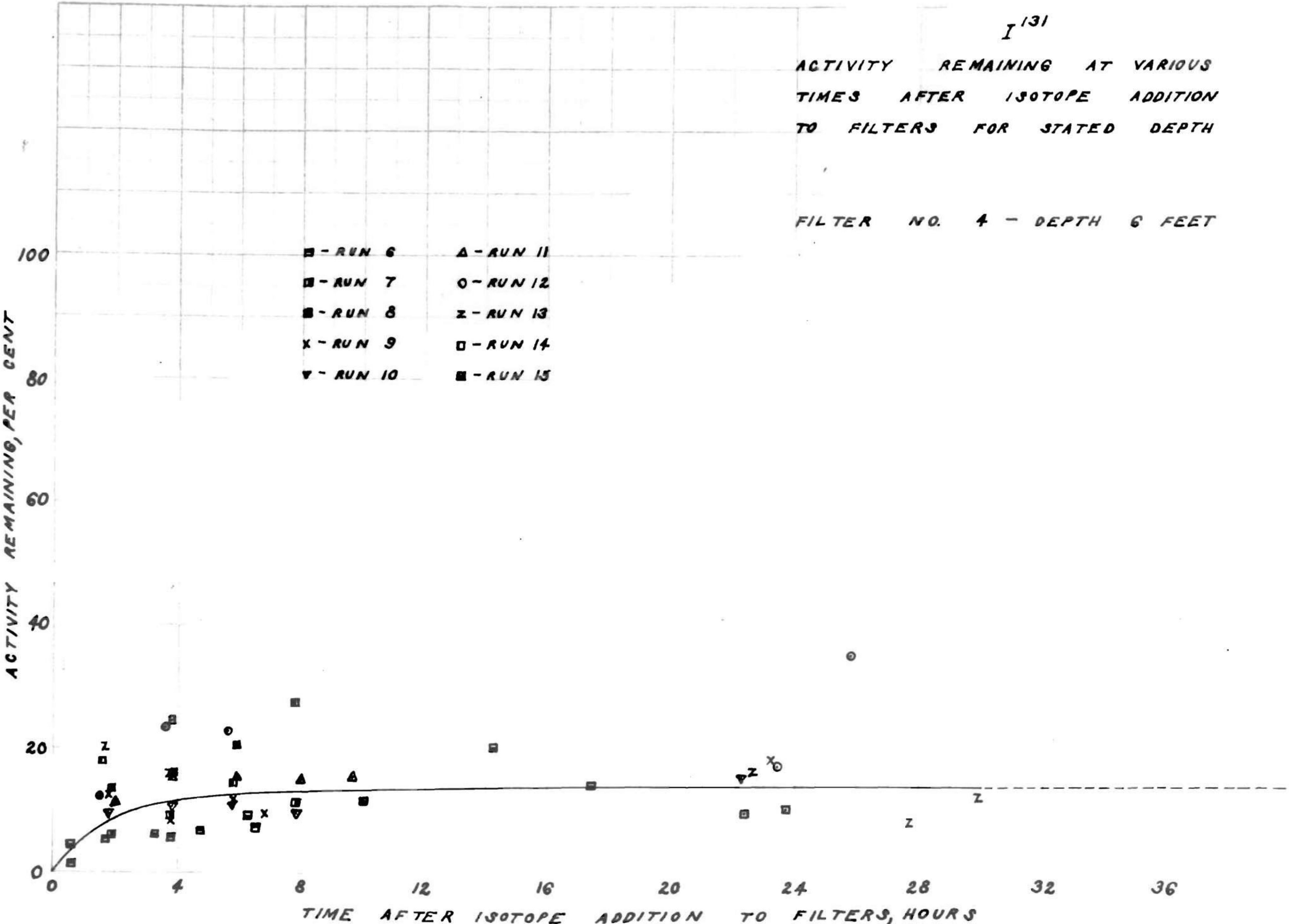

I 131
ACTIVITY REMAINING AT VARIOUS TIMES AFTER ISOTOPE ADDITION TO FILTERS FOR STATED DEPTH
FILTER NO. 2 - DEPTH 5 FEET
o - RUN 12
z - RUN 13
□ - RUN 14
■ - RUN 15
ACTIVITY REMAINING, PER CENT
0
20
40
60
80
100
0
4
8
12
16
20
24
28
32
36
TIME AFTER ISOTOPE ADDITION TO FILTERS, HOURS

FIGURE 15



$I^{131}$
ACTIVITY REMAINING AT VARIOUS TIMES AFTER ISOTOPE ADDITION TO FILTERS FOR STATED DEPTH
FILTER NO. 2 – DEPTH 6 FEET
– RUN 1
– RUN 2
– RUN 3
– RUN 4
– RUN 5
– RUN 6
– RUN 7
– RUN 8
X – RUN 9
– RUN 10
– RUN 11
O – RUN 12
Z – RUN 13
– RUN 14
– RUN 15
ACTIVITY REMAINING, PER CENT
100
80
60
40
20
0
0
4
8
12
16
20
24
28
32
36
TIME AFTER ISOTOPE ADDITION TO FILTERS, HOURS


FIGURE 16



$I^{131}$
ACTIVITY REMAINING AT VARIOUS TIMES AFTER ISOTOPE ADDITION TO FILTERS FOR STATED DEPTH
FILTER NO. 4 - DEPTH 6 FEET
- RUN 6
- RUN 7
- RUN 8
x - RUN 9
▼ - RUN 10
△ - RUN 11
O - RUN 12
Z - RUN 13
□ - RUN 14
- RUN 15
ACTIVITY REMAINING, PER CENT
0
20
40
60
80
100
0
4
8
12
16
20
24
28
32
36
TIME AFTER ISOTOPE ADDITION TO FILTERS, HOURS


FIGURE 17

These figures show the relationship of per cent activity remaining with time after isotope addition to the filters for various filter depths. These curves were drawn by plotting the raw data and then passing a smooth curve through the mean of the points. The fluctuations mentioned previously in conjunction with B.O.D. results are also apparent here. Additional factors, such as original concentration of $I^{131}$, quantity and condition of solids in the sewage, quality of filter with respect to previously added activity and sloughing, must also be recognized.

Figures 9 through 17 seem to substantiate some of the factors mentioned. It is evident from these curves that the variation from run to run is much greater than the variation in the data from a single run. The single run data seem to be fairly consistent for any particular run.

Straub[39] has shown that sewage solids will remove $I^{131}$ during 24- to 48-hour contact periods, and this is also apparent from the results obtained by the writer. A feed solution having a concentration of approximately 1,000 c/m/ml was allowed to stand quiescent over a week end; sludge samples were then taken, and the resulting concentration was approximately $1 \times 10^5$ c/m/g of sludge on a dry weight basis.

Sloughing of the filter has a decided effect on the results obtained from grab samples. Since the slimes concentrate $I^{131}$, their periodic sloughing may make large differences in the counts obtained from effluent samples. For example, counts were obtained which were two- to three-fold higher than average when counting samples containing several nematode worms (discharged with the effluent).

The curves represent varying numbers of runs due to the nature of this project. Some runs were exploratory in nature while others consisted of the operation of one or two filters. Another factor is that the number of depths sampled varied from run to run.

Extrapolation of these curves, as shown by dotted lines, yields an equilibrium value which is reached when the per cent activity remaining is constant with time after isotope addition to the filters. It is evident that equilibrium conditions have been approached for the one-foot depth after a minimum of 32 hours has elapsed since the addition of the isotope. Equilibrium is approached faster at the greater filter depths and is evident after about 20 hours at a depth of six feet.

This state of equilibrium is more readily noticed by referring to Figures 18 and 19. These figures were composited from Figures 9 through 17 and are plotted for filters No. 2 and 4, respectively. The curves indicate that 85 per cent of the activity may be removed during passage through the filter at a dosage rate of 2 mgad.

At the origin, the curves shown in Figures 9 through 19 are not accurate. Actually, there is a very definite time lag of a few minutes associated with each curve. This time lag is a maximum for the six-foot depth and a minimum for the one-foot depth. "Time zero" was taken at the time the spiked sewage went on the filters, and thus a short time-period is required before radioactive effluent samples may be obtained.

A comparison of $I^{131}$ percentage removal with B.O.D. removal as indicated by the first phase of this work (Figure 8 -- 2 mgad) is given in Figure 20. B.O.D. removal in general is higher for a particular depth, with the three-foot depth being an exception. At this depth and also at the two-foot depth, the removals of B.O.D. and activity are

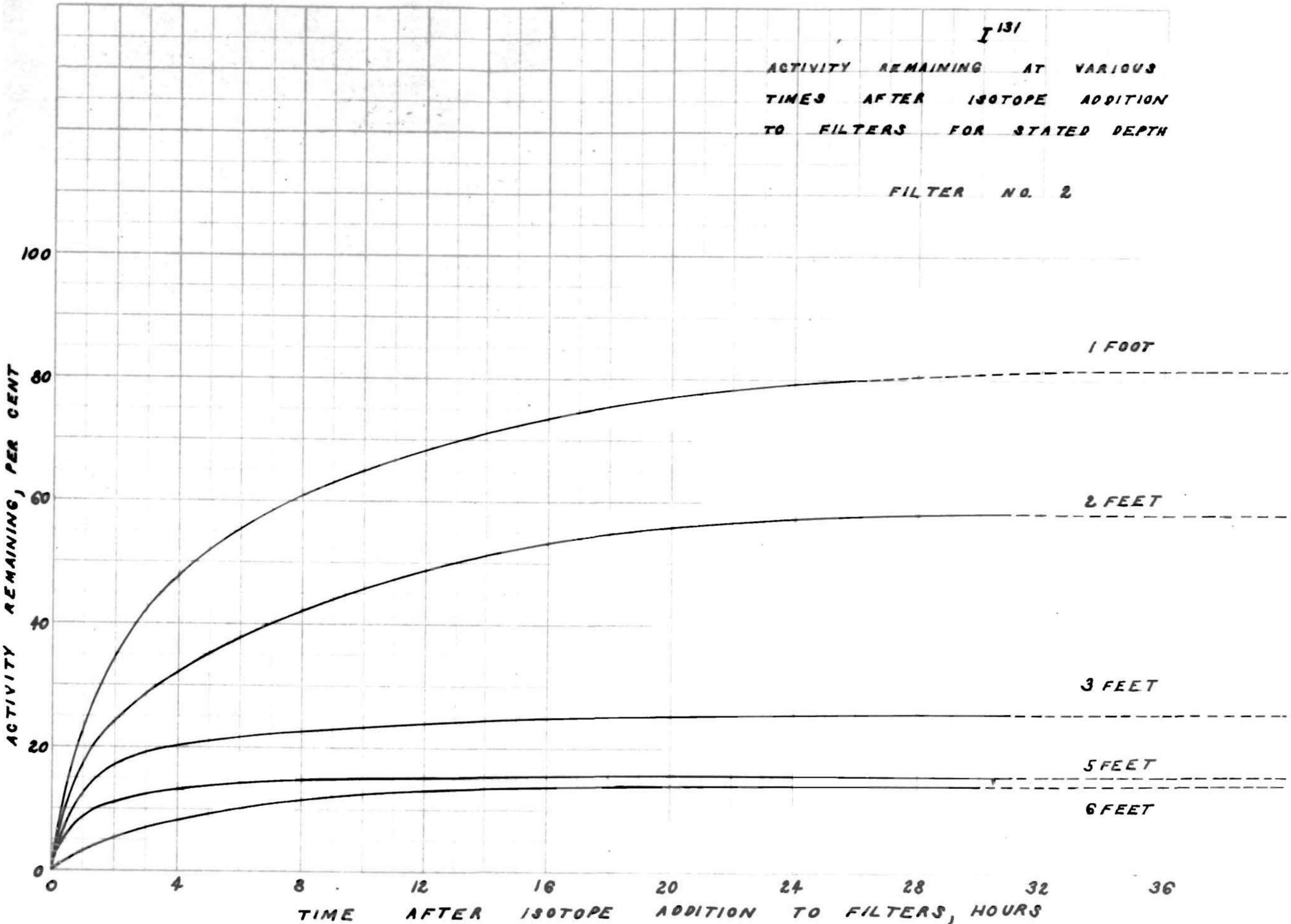

I131
ACTIVITY REMAINING AT VARIOUS TIMES AFTER ISOTOPE ADDITION TO FILTERS FOR STATED DEPTH
FILTER NO. 2
1 FOOT
2 FEET
3 FEET
5 FEET
6 FEET
ACTIVITY REMAINING, PER CENT
0
20
40
60
80
100
0
4
8
12
16
20
24
28
32
36
TIME AFTER ISOTOPE ADDITION TO FILTERS, HOURS

FIGURE 18

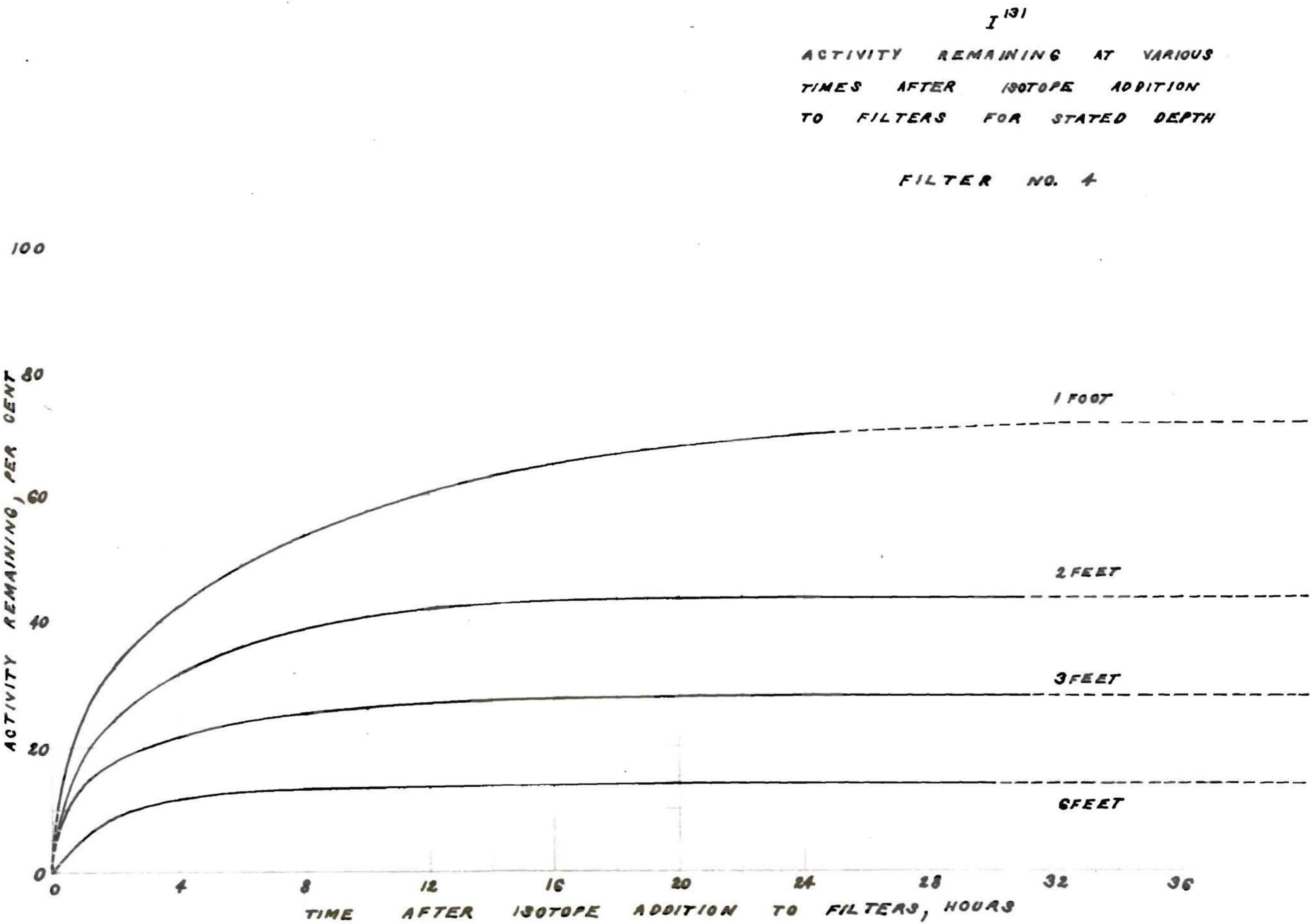
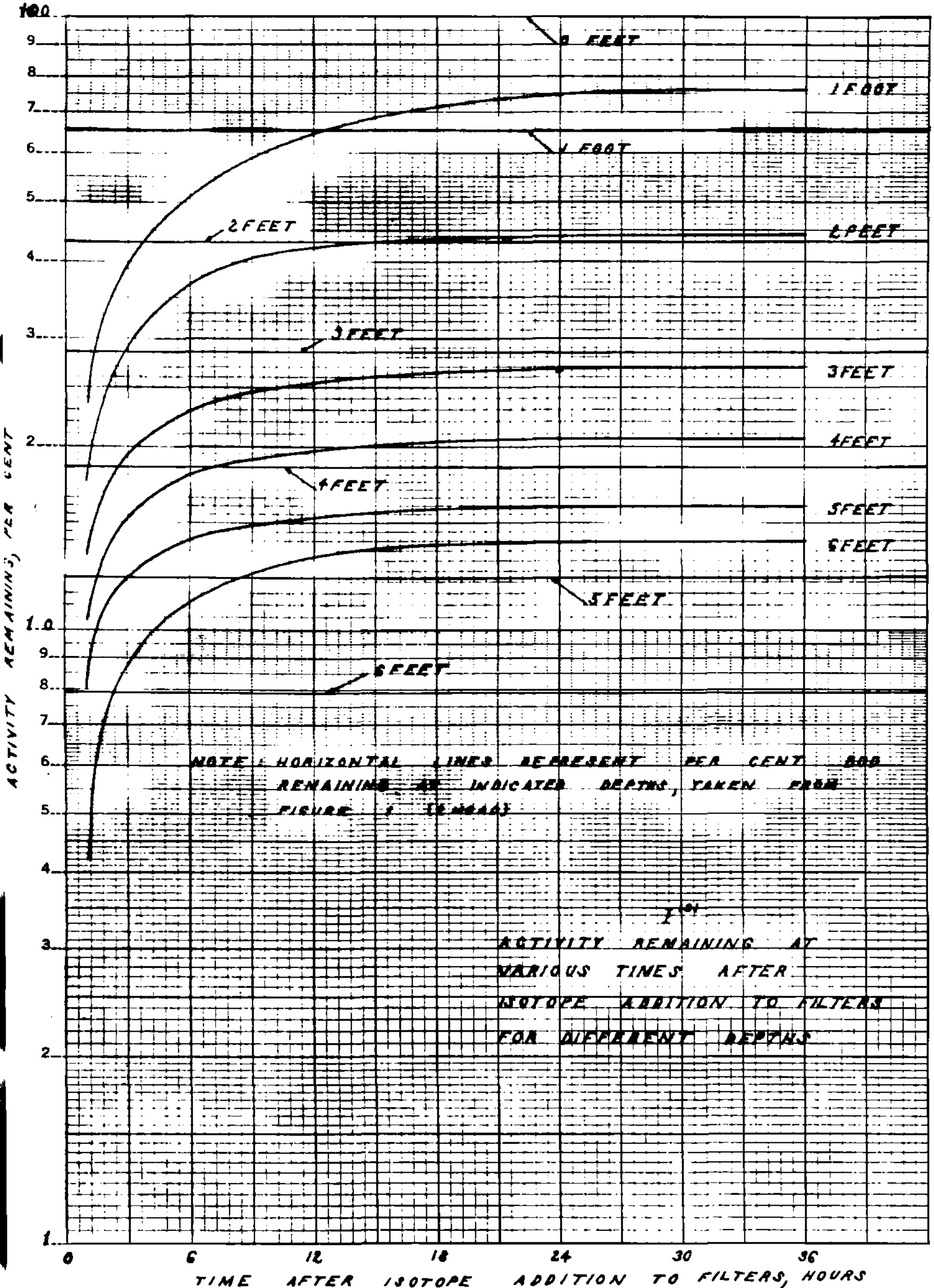

I 131
ACTIVITY REMAINING AT VARIOUS TIMES AFTER ISOTOPE ADDITION TO FILTERS FOR STATED DEPTH
FILTER NO. 4
100
80
60
40
20
0
ACTIVITY REMAINING, PER CENT
1 FOOT
2 FEET
3 FEET
6 FEET
0
4
8
12
16
20
24
28
32
36
TIME AFTER ISOTOPE ADDITION TO FILTERS, HOURS

FIGURE 19

FIGURE 20




$I^{131}$ ACTIVITY REMAINING AT VARIOUS TIMES AFTER ISOTOPE ADDITION TO FILTERS FOR DIFFERENT DEPTHS almost identical. At the five- and six-foot depths B.O.D. removal is considerably higher than $I^{131}$ removal.

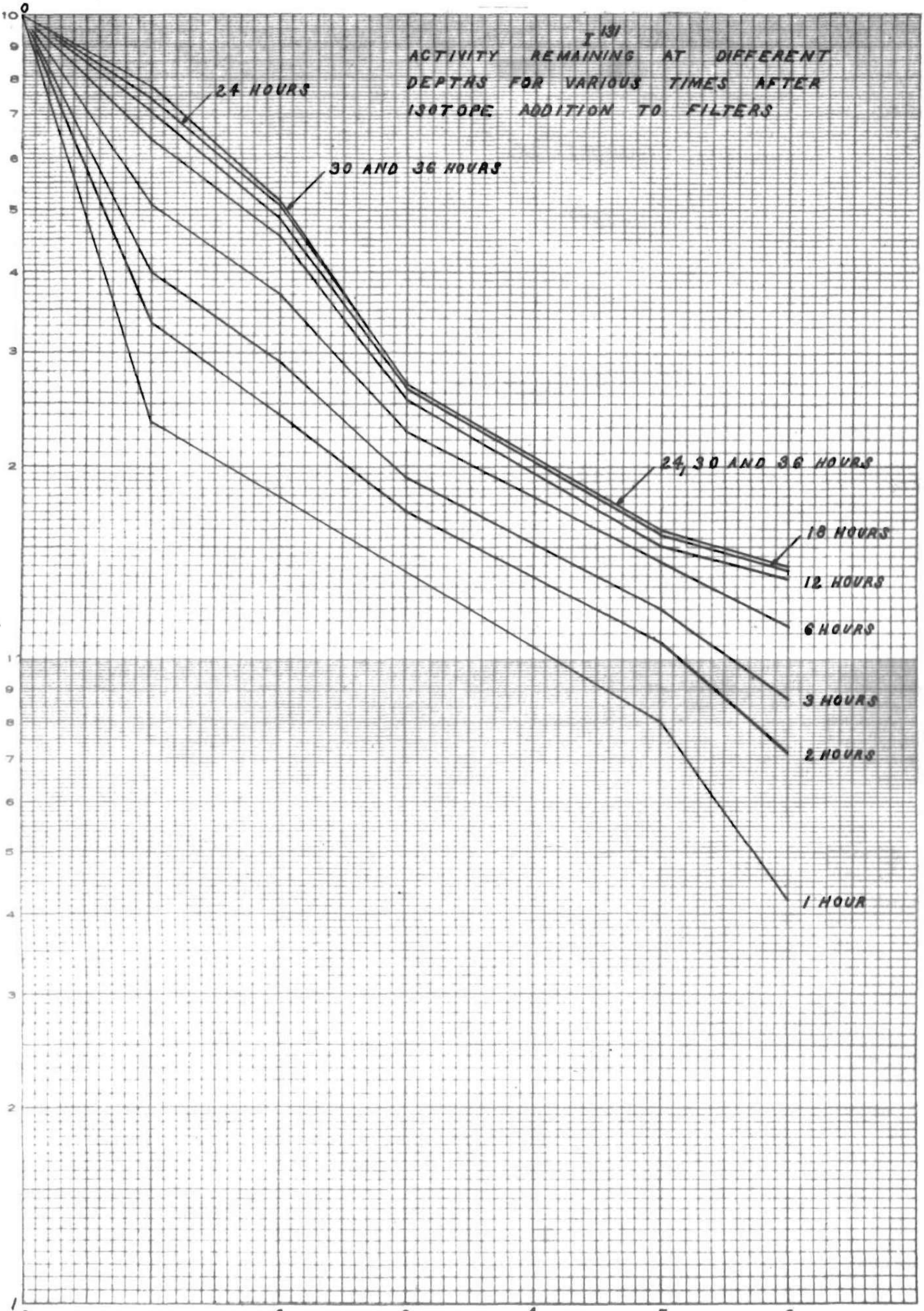
That these differences exist would indicate that factors other than those affecting B.O.D. removal are involved. These factors, mentioned in conjunction with data fluctuation, seem to be original concentration of $I^{131}$, quantity and condition of solids in the feed, quality of filter in respect to previously added activity, and sloughing of filter.

This family of curves (Figure 20) also indicates the uneven rate of removal of $I^{131}$ by successive one-foot increments of depth. The horizontal lines are taken from Figure 8 at a dosage rate of 2 mgad and show that B.O.D. removal per unit of depth is a constant amount of the B.O.D. remaining, the quantity of B.O.D. coming on to that particular increment of depth.

The curves are not equally spaced, and therefore the removal is not a constant amount of the $I^{131}$ activity remaining. Curves for the three-, four-, and five-foot depths indicate a constant removal (equally spaced), but this is most likely faulty since no samples were taken at the four-foot depth. This was due to erratic valves at this depth in filters No. 2 and 4, and this fact also resulted in no samples being taken from the five-foot depth of filter No. 4.

The rates of removal may best be seen by reference to Figure 21 and Table XI. Figure 21 shows the rates of removal at different depths and times after isotope addition to the filters. These valves -- slopes -- are tabulated for convenience in Table XI.

FIGURE 21



$I^{131}$
ACTIVITY REMAINING AT DIFFERENT DEPTHS FOR VARIOUS TIMES AFTER ISOTOPE ADDITION TO FILTERS
24 HOURS
30 AND 36 HOURS
24, 30 AND 36 HOURS
18 HOURS
12 HOURS
6 HOURS
3 HOURS
2 HOURS
1 HOUR
ACTIVITY REMAINING, PER CENT
FILTER DEPTH, FEET
0
1
2
3
4
5
6
10
9
8
7
6
5
4
3
2
1

TABLE XI

SLOPE PER UNIT DEPTH OF FILTER AT VARIOUS TIMES
AFTER ISOTOPE ADDITION TO FILTERS

| Filter Increments (ft) | Slope per Unit Depth of Filter at Stated Times after Isotope Addition to Filters | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 hr | 2 hrs | 3 hrs | 6 hrs | 12 hrs | 18 hrs | 24 hrs | 30 hrs | 36 hrs |
| 0 - 1 | 0.629 | 0.474 | 0.398 | 0.288 | 0.191 | 0.149 | 0.128 | 0.114 | 0.114 |
| 1 - 2 | 0.126 | 0.146 | 0.140 | 0.144 | 0.151 | 0.164 | 0.170 | 0.179 | 0.179 |
| 2 - 3 | 0.121 | 0.152 | 0.179 | 0.212 | 0.255 | 0.264 | 0.291 | 0.276 | 0.276 |
| 3 - 4 | 0.111 | 0.101 | 0.101 | 0.103 | 0.113 | 0.115 | 0.115 | 0.115 | 0.115 |
| 4 - 5 | 0.110 | 0.104 | 0.103 | 0.101 | 0.114 | 0.115 | 0.112 | 0.112 | 0.112 |
| 5 - 6 | 0.280 | 0.175 | 0.139 | 0.099 | 0.049 | 0.056 | 0.061 | 0.061 | 0.061 |

The rates of removal fluctuate less and less with an increase in time after addition of the isotope. The five- to six-foot increment for one, two, and three hours after isotope addition to filters seems to deviate sharply from what would be expected. One possible explanation lies in the fact that only one filter was sampled at a depth of five feet. Thus, this could possibly affect the location of the points at the five-foot depth. It should be noted that these points are mean values, and the curves would be quite different if smooth lines were drawn within the range of the maximum and minimum values.

Table XII gives the rate of change per hour of the removal rate per unit depth of filter. Two things are evident from this table: (1) when the values are zero or very small, equilibrium conditions have been approached; and (2) the sign indicates whether the rate of removal has increased or decreased. Thus, for the zero- to one-foot increment the rate of removal is decreasing but at a decreasing rate.

Since these spiked sewage runs were quite time consuming, all data are included. No limiting factor is placed on the dosage rates such as that used for B.O.D. dosage rate data.

Table XIII presents meager data on pH values. Spot pH checks were made at other times and their values were always above a pH of seven on both influent and effluent samples. Therefore, as far as is known all samples had pH values slightly on the basic side.

Some discrepancy in results has been obtained by several groups working with $I^{131}$ in waste disposal problems. The Cincinnati Group[40] has found low removals of $I^{131}$ from waste materials, while Straub[41] reports relatively high removals in his work using trickling filters and activated

TABLE XII

CHANGE OF SLOPE PER UNIT DEPTH OF FILTER PER HOUR FOR VARIOUS INTERVALS OF TIME AFTER ISOTOPE ADDITION TO FILTERS

| Filter Increments (ft) | Change of Slope per Unit Depth of Filter per Hour for Stated Intervals of Time after Isotope Addition to Filters | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1-2 hrs | 2-3 hrs | 3-6 hrs | 6-12 hrs | 12-18 hrs | 18-24 hrs | 24-30 hrs | 30-36 hrs |
| 0 - 1 | -0.155 | -0.076 | -0.037 | -0.016 | -0.007 | -0.004 | -0.002 | 0 |
| 1 - 2 | 0.020 | -0.006 | 0.001 | 0.001 | 0.002 | 0.001 | 0.002 | 0 |
| 2 - 3 | 0.031 | 0.027 | 0.011 | 0.007 | 0.002 | 0.005 | -0.003 | 0 |
| 3 - 4 | 0.010 | 0 | 0.001 | 0.002 | 0 | 0 | 0 | 0 |
| 4 - 5 | -0.006 | -0.001 | -0.001 | 0.002 | 0 | -0.001 | 0 | 0 |
| 5 - 6 | -0.105 | -0.036 | -0.013 | -0.008 | 0.001 | 0.001 | 0 | 0 |

TABLE XIII

pH DATA

| Date | Material | Temperature (°C) | pH |
| --- | --- | --- | --- |
| 7/28/50 | Raw Sewage | 22.6 | 7.83 |
| | Settled Sewage | 24.7 | 7.83 |
| | Effluent $E^1$ | 24.7 | 7.92 |
| | Effluent $E^2$ | 24.7 | 7.68 |
| | Effluent $E^3$ | 24.7 | 7.80 |
| | Effluent $E^4$ | 24.7 | 7.85 |
| 11/1/50 | Raw Sewage | 21.0 | 7.64 |
| | Settled Sewage | 23.1 | 7.63 |
| | Effluent $E^2$ | 23.2 | 7.57 |
| | Effluent $E^4$ | 23.2 | 7.61 |
| 12/18/50 | Effluent $E^2$ | 22.9 | 7.70 |
| | Effluent $E^4$ | 22.8 | 7.64 |

sludges; and also, there are the results presented here. As a possible explanation for these differences, Dr. C. P. Straub, Sanitary Engineer, Public Health Service, on loan to Oak Ridge National Laboratory, has recently completed tests (using the trickling filters employed in this study) to determine the effect of isotopic dilution on filter efficiency. Figure 22 presents a summation of his findings. These studies were made with settled sewage having an $I^{131}$ concentration of approximately 800 c/m/ml. The four graphs for filters No. 1, 2, 3, and 4 show removals of $I^{131}$ obtained using no KI, 25 ppm KI, 50 ppm KI, and 100 ppm KI. These quantities of diluents are considerably in excess of those recommended by the Isotopes Division, A.E.C.[42] -- namely, one gram of KI/mc of $I^{131}$ discharged. These values are 6.7, 13.4, and 26.8 times those recommended and are presented for filters No. 4, 2, and 3, respectively, in Figure 22.

Using dosage rates varying between 4.1 to 4.45 mgad, Straub obtained removal of 50 per cent of the $I^{131}$ when using no diluent. The removals were reduced considerably, down to as low as five per cent when isotopic dilution was used as shown for filter No. 2. He also ran a test on the carboy-precipitated solids and found that in the carboy containing no KI the concentration of $I^{131}$ on the solids was approximately 10 times that of the solids in the other three carboys containing the excessive quantities of KI.

These results are contrary to the results reported by Talboys.[43] His experimental studies led him to the conclusion that isotopic dilution is ineffective on the concentration of $I^{131}$ by sewer system slimes.

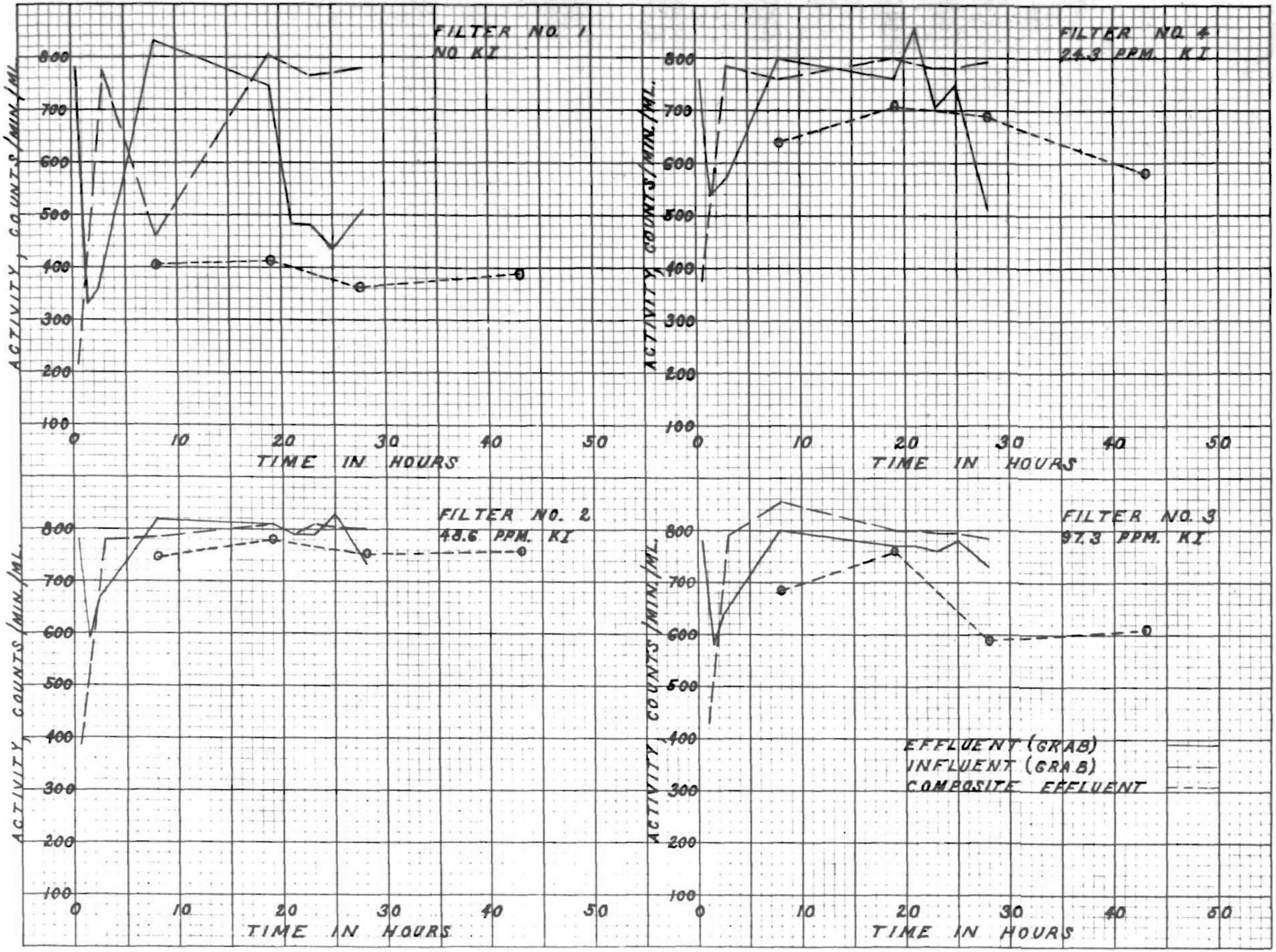



FIGURE 22

EFFECT OF CARRIER KI ON REMOVAL OF $I^{131}$ BY TRICKLING FILTERS

If it is assumed that the results as presented here are accurate, then certain calculations may be made. These will be based on the $I^{131}$ concentration used (1,000 c/m/ml) dosage rate of 2 mgad and 85 per cent removal of $I^{131}$. It may be added that further removals would most likely be accomplished if the filter effluent were treated by secondary settling or sand filtration, or both. This would be possible if the waste to be treated in such a manner contained suspended solids which were radioactive due to the presence of $I^{131}$.

With our conditions, the final filter effluent would contain 150 c/m/ml, and assuming 10 per cent geometry we would have 1,500 disintegrations per m/ml. This is equivalent to 25 disintegrations per sec/ml. Converting to $\mu$c by dividing by $3.7 \times 10^4$ we have a concentration of $7 \times 10^{-4}$ $\mu$c/cc. Taking Morgan's value for maximum permissible concentration of $1 \times 10^{-7}$ $\mu$c/cc of $I^{131}$ (since $I^{131}$ is primarily a $\beta$ emitter) in water, we see that the filter effluent contains $7 \times 10^3$ times tolerance value.[44]

This reduction of 85 per cent does not seem to be adequate and isn't for direct discharge; but, if this waste were then treated by water dilution the reduction would be apparent. It would require six to seven times more diluent water if the waste were untreated by the filters.

If trickling filters of this type were installed to treat a similar waste, then this waste should be treated prior to isotopic dilution. Further work on this specific problem seems needed and should be directed towards treatment of actual waste -- for example, hospital waste containing $I^{131}$ and the effects of secondary settling and sand filtration on the filter effluents. The same general type study could be made on the several types of high rate filters.

# PROBLEMS AND SPECIAL INVESTIGATIONS

## Unusual Filter Sloughing and Corrective Measure Taken

On September 8, 1950, it was noticed that filters No. 1 and 3 were devoid of practically all their normal film accumulation. This was the result of sloughing due to an unknown cause. Since rapid rehabilitation was desirable, the opportunity was taken of discussing this matter with Mr. C. C. Ruchhoft[45] on his visit to Oak Ridge National Laboratory, September 15, 1950.

He suggested fortifying the sewage feed with a mixture of dextrose and flour in a 1:4 weight ratio, respectively. (The recommended feed was 200 ppm). This was immediately tried and filters No. 1 and 3 were rehabilitated in about two weeks time.

During the rehabilitation period, the filter slimes were much lighter in color than those of filters No. 2 and 4. They were a dirty cream color at first and gradually darkened, presumably with the accumulation of sewage solids and perhaps with the maturing of, or changes in the filter population.

It is regrettable that no tests were made during this period, since it would have been interesting to study the rehabilitation of a trickling filter using a combination of natural (that contained in domestic sewage) and artificial (that contained in dextrose and flour) food materials.

## Growth of Slimes in Influent Feed Lines

It was noted on one occasion that removals of B.O.D. were unusually high. There seemed to be no relation between filter depth, dosage rate, and B.O.D. removed. This is mentioned previously in the section "Filter Influent Sampling" (page 23) and also in the section "Preliminary Phase of Work - B.O.D. Results" (page 31). The cause for this was thought to be excessive slime growths in the feed lines. This matter was discussed with members of the Waste Disposal Group and the concensus of opinion seemed to favor the use of chlorine.

A solution of chlorine (100 ppm) was fed through the lines for a period of one hour. Near the end of this period, all parts of the influent lines were massaged by kneading and rubbing the tubes. Next, the tubes were flushed out for a suitable time with settled sewage at a high rate of flow. The massaging was repeated during the flushing period.

This technique gave satisfactory results and was adopted as a standard procedure to be used every two weeks. After employing this corrective measure, no more trouble was experienced with influent line slime growth.

## Results on Slime Concentration of $I^{131}$

Table XIV shows the results on filter slime concentration of $I^{131}$. These data are significant in that the concentration factor is 500 to 1,000. The concentration of $I^{131}$ in the influent was always approximately 1,000 c/m/ml, while the slime concentration $I^{131}$ was approximately $1 \times 10^6$ c/m/g on a dry weight basis. This concentration amounts to about 300 $\mu$c/dry-gram or 0.3 mc/dry-gram. In large filters, this concentration in a relatively large quantity of material could produce a very definite radiation hazard.

The data in Table XIV were obtained by taking the stones from the top three inches of filter and then brushing the slimes off into beakers

TABLE XIV

FILTER SLIME CONCENTRATION OF $I^{131}$

Date: 12/18/50 Background: 28 C/M

| Sample No. | Filter No. | Recorder Reading (value x 64) | Lights (counts) | Counting Time (min) | Counts per Minute (C/M) | C/M Corrected for Background (CCB) | Sample Weight (grams) | Counts per Minute per Dry-Gram* (c/m/dry-gram) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 113 | 56 | 3 | 2429 | 2401 | 0.0127 | 189,000 |
| 2 | 2 | 146 | 0 | 2 | 4672 | 4644 | 0.0225 | 206,000 |
| 3 | 2 | 190 | 6 | 2 | 6083 | 6055 | 0.0599 | 101,000 |
| 1 | 4 | 184 | 17 | 2 | 5891 | 5863 | 0.0331 | 177,000 |
| 2 | 4 | 121 | 30 | 2 | 3887 | 3859 | 0.0199 | 194,000 |
| 3 | 4 | 127 | 42 | 1 | 8170 | 8142 | 0.0406 | 201,000 |

*The magnitudes of these data are increased approximately five-fold when decay is taken into consideration.

utilizing small amounts of water in the process. The fluctuations in the results (c/m/dry-gram) are thought to be caused by the differences in sample weights. This is brought about by self-absorption in the sample. Thus, there is a very definite value of sample weight which will yield the most accurate count. It is noted that the heaviest sample, No. 3 for filter No. 2, has the lowest concentration. Excepting sample No. 3 for filter No. 4, this theory is fairly closely borne out. Under the counting conditions existent, it would appear that a sample weight of approximately 0.02 grams is the best choice for sample weight.

Table XV contains data obtained from tests (counts) on the effluent from the feed lines during chlorination. This chlorination process has been discussed previously in this section.

Assuming that some washing action takes place in the chlorination process, it is evident that only a small portion of the activity is contained in the supernatant. This would tend to indicate that the $I^{131}$ was either fastly absorbed, adsorbed, or assimilated or a combination of these processes. Here again, we find a concentration factor of approximately 1,000.

## Sloughing as Related to $I^{131}$ Discharge

Table XVI presents limited data on the effects of sloughing in the carry-over of $I^{131}$ in filter effluent. The samples were collected 10 days after any isotope had been added to the filters. It is noted that the filter effluent still contains small amounts of $I^{131}$. These counts could no doubt be reduced if sand filtration of filter effluent were practiced.

TABLE XV

DATA ON EFFLUENT FROM CHLORINATED FEED LINES

Date: 10/31/50 Background: 29 C/M

| Sample No. | Recorder Reading (value x 64) | Lights (counts) | Counting Time (min) | Counts per Minute (C/M) | C/M Corrected for Background (CCB) | Sample Size | Counts per Minute per Dry-Gram or ml (c/m/dry-gram or ml) |
|---|---|---|---|---|---|---|---|
| Sludge | 43 | 40 | 5 | 558 | 529 | 0.0507 g | $1.04 \times 10^4$ |
| Sludge | 39 | 43 | 5 | 508 | 479 | 0.0425 g | $1.13 \times 10^4$ |
| Sludge | 27 | 44 | 5 | 354 | 326 | 0.0313 g | $1.04 \times 10^4$ |
| Supernatant | 10 | 27 | 5 | 133 | 105 | 10 ml | 11 |
| Supernatant | 9 | 46 | 5 | 124 | 96 | 10 ml | 10 |

TABLE XVI

RESULTS ON FILTER SLOUGHING

Date: 12/18/50 Background: 28 C/M

| Sample No.* | Filter No. | Recorder Reading (value x 64) | Lights (counts) | Counting Time (min) | Counts per Minute (C/M) | C/M Corrected for Background (CCB) | Sample Volume (ml) | Counts per Minute per Milliliter (c/m/ml) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 10 | 26 | 5 | 133 | 105 | 10 | 11 |
| 2 | 2 | 11 | 42 | 5 | 149 | 121 | 10 | 12 |
| 3 | 2 | 11 | 39 | 5 | 149 | 121 | 10 | 12 |
| 1 | 4 | 12 | 7 | 5 | 155 | 127 | 10 | 13 |
| 2 | 4 | 11 | 40 | 5 | 149 | 121 | 10 | 12 |
| 3 | 4 | 12 | 17 | 5 | 157 | 129 | 10 | 13 |

*All samples taken from filter effluents.

Presence of Nematode Worms in Filter Effluent

Nematode worms are considered to belong to the "scouring group" of organisms found in trickling filters. Their presence in this investigation was especially noted when the loading rate (dosage rate) was decreased. Several factors are involved. First, the velocity of flow is decreased and hence the worms would find it easier to remain in the slimes. Second, the food supply is decreased which would tend to reduce their numbers in the filter. Third, there are other factors such as aerobic or anaerobic conditions which would have to be considered. This is not intended to be even a brief discussion of this phenomenon, but to propose possibly another factor. Is it not possible that these nematode worms are exercising negative chemotropism to the products of nitrification?

Determination of Copper

In surveying for a water suitable for dilution water, copper determinations had to be made on each prospective source. The determination was made according to Standard Methods for the Examination of Water and Sewage.[32] To be used for dilution water, water must contain less than 0.01 ppm Cu.

The results obtained on tap water and distilled water, as supplied to our laboratory, are as follows:

| Source of Water | Colorimeter Reading | Copper Concentration |
|---|---|---|
| Tap | 86.5 | $>$ 0.01 ppm |
| Distilled | 99.7 | $<$ 0.01 ppm |

## CONCLUSIONS

Based on the conditions existent during this study and in accordance with the techniques used, several conclusions are warranted.

1. The laboratory trickling filters seem to have operated normally in respect to B.O.D. removal.

2. Carrier-free $I^{131}$ (obtained from the Operations Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee) may be partially removed from contaminated sewage by the use of trickling filters.

3. $I^{131}$ removal in excess of 85 per cent was obtained at a dosage rate of two million gallons per acre per day.

4. Factors other than those effecting B.O.D. removal are involved and most likely include the following:

   (a) Concentration of radioactivity.
   (b) Quantity and condition of solids in feed solution.
   (c) Quality of filter in respect to previously added activity.
   (d) Sloughing.
   (e) Presence or absence of stable iodine in the sewage.

5. Sewage solids are effective in the take-up of small quantities of $I^{131}$.

6. Chlorination is effective in the control of slime growth in rubber tubes such as those used in this investigation for feed lines.

7. Secondary settling or sand filtration or both for the removal of suspended solids should be investigated in conjunction with trickling filters when treating sewages contaminated with radioactive $I^{131}$.

8. Rapid rehabilitation of trickling filters, following sloughing, is possible even though working with a weak sewage by using "artificial" food materials. Those used successfully in this study were dextrose and flour in a 1:4 weight ratio, using a total concentration of 200 ppm.

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# APPENDIX

# APPENDIX

## SAMPLE CALCULATIONS

### Filter Area Calculation

Data: Inside diameter of filter (d) = 2 inches

Calculation:

$$\text{Area} = \frac{\pi d^2}{4}$$

$$= \frac{\pi}{4}\left(\frac{2 \text{ in x ft}}{12 \text{ in}}\right)^2 \text{ x } \frac{\text{acre}}{43{,}560 \text{ ft}^2}$$

$$= 0.5 \text{ x } 10^{-6} \text{ acre}$$

### Dosage Rate Calculation for Run No. 3, Table II (see page 32)

Data: Time of Flow (t) = 126 minutes
Vol. of Flow (v) = 335 milliliters

Calculation:

$$\text{Rate of Flow} = \frac{v}{t}$$

$$= \frac{335 \text{ ml}}{126 \text{ min}} = 2.66 \text{ ml/min}$$

$$= 2.66 \text{ ml/min x } \frac{1}{1000 \text{ ml}} \text{ x } \frac{\text{gal}}{3.791} \text{ x } \frac{\text{mg}}{10^6 \text{gal}} \text{ x } \frac{1440 \text{ min}}{\text{day}}$$

$$= 1.01 \text{ x } 10^{-6} \text{ mg/day}$$

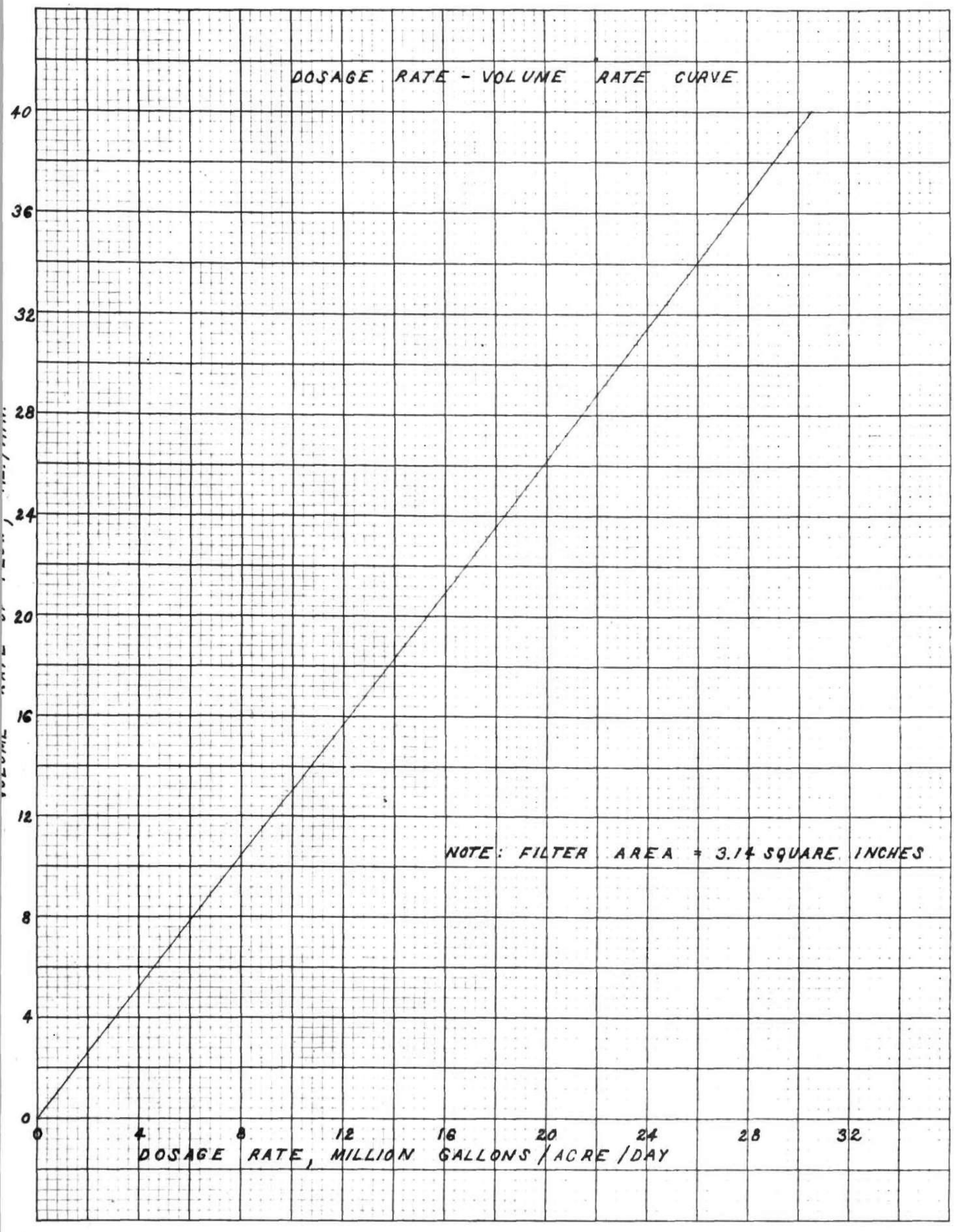
$$\text{Dosage Rate} = \frac{\text{Rate of Flow}}{\text{Filter Area}}$$

$$= \frac{1.01 \text{ x } 10^{-6} \text{ mg/day}}{0.5 \text{ x } 10^{-6} \text{ acre}}$$

$$= 2.02 \text{ mgad}$$

(NOTE: Dosage rates were taken from Figure 23.)

FIGURE 23


DOSAGE RATE - VOLUME RATE CURVE
NOTE: FILTER AREA = 3.14 SQUARE INCHES
DOSAGE RATE, MILLION GALLONS / ACRE / DAY
0
4
8
12
16
20
24
28
32
36
40

B.O.D. Calculation for Run No. 1, Table IV (see page 35)*

Data: Volume of $Na_2S_2O_3$ used in titration of sample 7I5 before incubation ($V_1$) = 7.34 milliliters

Volume of $Na_2S_2O_3$ used in titration of sample 12I5 after 5 days incubation ($V_2$) = 2.55 milliliters

Normality of $Na_2S_2O_3$ (N) = 0.0254

Per cent dilution (%) = 5

Amount of sample titrated = 202 milliliters

Calculation:

Initial Dissolved Oxygen Present = $D.O._1$
Final Dissolved Oxygen Present = $D.O._2$

$$D.O._1 = V_1 \times \frac{0.0254}{0.0250}$$

$$= V_1 \times 1.016 = 7.34 \times 1.016$$

$$= 7.46 \text{ ppm}$$

$$D.O._2 = V_2 \times \frac{0.0254}{0.0250}$$

$$= V_2 \times 1.016 = 2.55 \times 1.016$$

$$= 2.59 \text{ ppm}$$

$$B.O.D. = \frac{D.O._1 - D.O._2}{\%} \times 100 \text{ ppm}$$

$$= \frac{7.46 - 2.59}{5} \times 100 \text{ ppm}$$

$$= 97.4 \text{ ppm}$$

Filter Efficiency Calculation for Run No. 3, Table II (see page 32)

Data: Influent B.O.D. (I) = 95.1 ppm
Effluent B.O.D. (E) = 37.0 ppm

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*Not according to Standard Methods for the Examination of Water and Sewage.

Calculation:

$$\text{B.O.D. Removed} = \left(\frac{I - E}{I}\right) 100$$

$$= 100 \left(\frac{95.1 - 37.0}{95.1}\right)$$

$$= \frac{58.1}{95.1} \times 100$$

$$= 61.1\%$$

$$\text{B.O.D. Remaining} = 100.0 - \text{B.O.D. Removed}$$

$$= 100.0 - 61.1$$

$$= 38.9\%$$

Calculations on Spiked Sewage Runs for Sample 15a-0-2, Tables IX and X (see pages 42 and 45)

Data: Background Count (average for 10 min) = 27 C/M

Recorder Reading = 154 (a)*
Recorder Reading = 155 (b)*

Lights = 33 counts (a)*
Lights = 1 count (b)*

Counting Times = 2 min (a)*
Counting Times = 2 min (b)*

Vol. of Samples (V) = 5 ml (a)*
Vol. of Samples (V) = 5 ml (b)*

Decay Correction Factor = 1.02 (taken from Figure 7, page 30)

Calculation:

Total Counts Registered (a) = (154 x 64) + 33 = 9,889
Total Counts Registered (b) = (155 x 64) + 1 = 9,921

Counts per Minute (a) = 9,889/2 = 4,945 C/M
Counts per Minute (b) = 9,921/2 = 4,961 C/M

C/M Corrected for Background (a) = C/M (a) - Background Count
= 4,945 - 27 = 4,918 CCB
C/M Corrected for Background (b) = C/M (b) - Background Count
= 4,961 - 27 = 4,934 CCB

---

*a and b refer to duplicate samples.

$$\text{Counts per Minute per Milliliter (a)} = \frac{CCB(a)}{V(a)} = \frac{4{,}918}{5} = 984 \text{ c/m/ml}$$

$$\text{Counts per Minute per Milliliter (b)} = \frac{CCB(b)}{V(b)} = \frac{4{,}934}{5} = 987 \text{ c/m/ml}$$

$$\text{Average c/m/ml} = \frac{984 + 987}{2} = 986 \text{ c/m/ml}$$

$$\text{Average c/m/ml Corrected for Decay} = 986 \times 1.02$$

$$= 1{,}006 \text{ c/m/ml}$$

(NOTE: The per cent initial activity remaining calculation is based on the average value of all the individual results at the "0" foot level, the influent as coming onto the filters.)

Average Concentration of $I^{131}$ in the Influent =

$$\frac{1006 + 1017 + 1013 + 1028 + 1013 + 1004}{6} =$$

$$1{,}014 \text{ c/m/ml}$$

Calibration and Results of Copper Determination

| Known Copper Concentration (ppm) | Transmittance of Colorimeter (%) |
|---|---|
| 10.0 | 0.3 |
| 1.0 | 28.9 |
| 0.02 | 94.6 |
| 0.01 | 96.0 |
| 0.005 | 97.5 |

Results on two waters are as follows:

| Source of Water | Actual Colorimeter Reading | Critical Colorimeter Reading | Status of Water |
|---|---|---|---|
| Tap | 86.5 | 96.0 | No Good |
| Distilled | 99.7 | 96.0 | O.K. |

Calculation for Volume of Voids for Sample No. 1, Table I (see page 10)

Data: Total Volume ($V$) = 3,700 milliliters
Volume of Voids ($V_V$) = 1,645 milliliters

Calculation:

$$\text{Volume of Voids} = \frac{V_V}{V} \times 100$$

$$= \frac{1,645}{3,700} \times 100$$

$$= 44.5\%$$